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Reusable Launch Vehicle Operations and Maintenance Guideline Inputs and Technical Evaluation Report: Maintenance - Volume 3

Final Report

Prepared for
Department of Transportation
Federal Aviation Administration
Associate Administrator for Commercial Space Transportation
AST-200 Licensing and Safety Division
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Washington, DC 20591

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Reusable Launch Vehicle Operations and Maintenance Guideline Inputs and Technical Evaluation Report:
Maintenance - Volume 3

Final Report

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Executive Summary

Development of commercial Reusable Launch Vehicles (RLVs) continues to be of great interest to many private companies. The appeal rests in an RLV's ability to support multiple mission types (e.g., cargo and "tourism") and amortize development costs over the life of the operational vehicle. Commercial RLV companies plan to use both existing and new technologies in the design/development of a launch system. RLV Operations and Maintenance (O&M) of new launch systems have the potential to affect public safety; therefore, the Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST) is in the process of developing preliminary guidelines for RLV O&M activities. These guidelines may be used to evaluate an RLV developer/operator's license application.

This Guideline Input and Technical Evaluation Report is intended to capture an initial set of Guideline Inputs (GIs) and Guideline Input Considerations (GICs) specific to the various functions associated with RLV maintenance, for any RLV concept, large or small, orbital or suborbital. This volume is the third of five such volumes; the first volume addressed RLV Subsystems; the second, RLV Operations; and the remaining 2 volumes address RLV O&M Training and Approval functions.

A total of three functions within the maintenance domain have been identified for development of maintenance guideline inputs. Each of these functions relate to a unique set of sub-functions for the maintenance of the RLV. The focus and intent of this task, Delivery Task (0002), has been to capture those tasks with potential public safety risks that should be considered relative to RLV maintenance. In order to ensure these guidelines have been considered, RTI proposes that a series of manuals be required as part of an RLV developer's final license application: Operations, Maintenance, Training, and Approval. These manuals would speak to the current requirements contained in the Code of Federal Regulations (CFR) for RLV Mission License Rule (14 CFR Part 431) and would also allow an RLV developer/operator to specify how they intend to address FAA/AST O&M Guidelines. In this way, the RLV developer/operator has the ability to stipulate which of these guidelines are relevant to their vehicle design and ensures that public safety considerations associated with RLV maintenance tasks, such as those in this volume, have been fully addressed.

In summary, the Guideline Inputs in this volume, and in the other four Guideline Input volumes, are intended to contribute to a common set of criteria by which the FAA and the RLV industry can assess public safety aspects of RLV O&M processes. As the industry matures, it is expected that additional guidelines will be developed; consequently, these Guideline Input volumes are considered to be living documents that will evolve as the RLV industry evolves.

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1.0 Introduction

Reusable Launch Vehicles (RLVs) will require guidelines and regulatory language to be developed for new approaches in both Operations and Maintenance (O&M). These approaches may have a direct effect on public safety where RLVs are being operated and maintained. This Guideline Input and Technical Evaluation Report is intended to capture an initial set of Guideline Inputs (GIs) and Guideline Input Considerations (GICs) ordered around the various functions associated with RLV maintenance, for any RLV concept, large or small, orbital or suborbital. This volume is the third of five such volumes: the first volume addresses RLV Subsystems; the second, RLV Operations; and the remaining 2 volumes address RLV Training and Approval Functions. The inputs identified in this volume, and in the other four Guideline Input volumes, contribute to a common set of criteria by which the FAA and the RLV industry can assess public safety aspects of RLV O&M processes. As the RLV industry matures, it is expected that additional guidelines will be developed, making these living documents that will evolve as the RLV industry evolves.

1.1 Purpose

The purpose of this document is to provide basic Guideline Inputs/Considerations for RLV maintenance, as well as a top-level introduction of the pertinent RLV maintenance functions. The intent is for these Guideline Inputs/Considerations to be general enough to be applicable for any RLV concept, large or small, orbital or suborbital. In this context, "pertinent" maintenance is considered any activity associated with an RLV's general/common maintenance tasks, unscheduled maintenance, and scheduled maintenance that has a potential to impact public safety. The functions identified here encompass activities associated with a variety of Concept of Operations (CONOPS) being proposed by the industry.

1.2 Background

These Guideline Inputs are the result of a focused effort by Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST) to facilitate a common understanding between both regulator and industry on what is expected from RLV operators and maintainers in order to ensure public safety. The creation of these Guideline Inputs was prompted by the response to an FAA/AST presentation of an RLV O&M White Paper to the Commercial Space Transportation Advisory Committee (COMSTAC) in October of 1999[1].

Industry feedback to that paper, along with FAA-directed research activities, led to the initiation of an information-only Rulemaking Project Record (RPR) intended to establish formal rules for RLV O&M. These Guideline Inputs represent an interim step toward a Notice of Proposed Rulemaking (NPRM) for RLV O&M and are intended to serve as a means by which those items requiring formalization as a rule can be identified and validated both by the FAA and by industry. However, it should be recognized that an NPRM would only be developed after the RLV industry is sufficiently mature.

RTI used the Systems Functions and Procedural Items identified during previous FAA tasking[2] as a starting point. It was determined that a general model was needed to place the Systems Functions and Procedural Items in context. These have been further developed in a subsequent tasking and now in this Order. A context diagram, Figure 1 in Section 1.5, was developed to provide this contextual framework, as well as provide a means of marrying the O&M top-down analysis, being completed by RTI, with the bottom-up analysis, being accomplished internally within the FAA.

1.2.1 Statement of Understanding

A Statement of Understanding (SOU) between the FAA and the RTI Team has been developed to govern each of the RLV O&M tasks. The following text presents the SOU developed for this effort:

> "The RTI Team will continue to support FAA/AST-100 in the development of RLV O&M guidelines and technical evaluation criteria.
>
> This task will build on the work accomplished in the RLV O&M Top-Down Analyses performed under DO2 and DO3 and complement the RLV O&M Guidelines developed under DO4 of the reference contract. In particular, the RTI Team will develop material to aid FAA/AST-100 identify the O&M technical evaluation criteria and performance standards for safety-critical RLV maintenance, training, and approval functions. In performing the specified work, particular attention will be made to any unique features, including proven and unproven RLV O&M activities, and their correlation to any historic lessons-learned in the Space Shuttle, airline and RLV research community.
>
> Under Order 0002, RTI will deliver the final guideline input volumes: Maintenance - Volume 3, Training – Volume 4, and Approval - Volume 5.
>
> The following summarizes specific topics that will be addressed:

1. Guideline inputs and rationale:
   The major RLV O&M subsystem and function safety items, as they pertain to the subject volumes, will be developed into guideline inputs along with the supporting rationale. These will be presented in the format approved by FAA/AST under DO4.
2. Further refinement of the Subsystem and Functional Decomposition:
   A number of modifications to the current Functional Decomposition diagrams have been identified including the need to add Functions for Contingency Operations, Vehicle Configuration Management, and Simulation Requirements. The Functional Decomposition diagrams will be modified to reflect the functional refinements, as required.
3. Continued data collection from the aviation and space domains:
   Continue to extract information from traditional aviation, the Space Shuttle, and other RLV programs in support of the guideline and technical evaluation criteria development."

1.3 Scope

The following Guideline Inputs are intended for use by the RLV Industry and the FAA's Office of Commercial Space Transportation in the preparation and evaluation of RLV license applications and O&M plans. The scope of these Guideline Inputs is bounded by the jurisdictional authority provided to the FAA by Congress 112 STAT. 2848 (Public Law 105-303-Oct. 28, 1998). Additionally, these Guideline Inputs do not affect or amend the content of the licensing rules, but rather are designed to help the FAA and RLV Industry jointly ensure the rules are both followed and applied in a consistent manner.

1.3.1 Guideline Input Philosophy

These Guideline Inputs have been developed to serve as a repository for best/recommended practices. It is expected that a portion of these practices will ultimately be formalized in a federal regulation that will govern the RLV Industry. Some inputs may be revisited as newer technologies are developed and better procedures emerge as the industry matures.

A wide variety of sources were reviewed and analyzed to develop the content of these Guideline Inputs. Primary consideration was given to lessons-learned drawn from the aviation and space community. In some cases, these lessons are explicit and are clearly technology-independent public safety issues and thus could be written as a requirement. In these cases, Guideline Inputs (GIs) have been developed and the term "shall" is used. These GIs are numbered sequentially with a Maintenance Function prefix (e.g., the first Perform Maintenance Guideline Input is numbered Perf Gen Maint GI-1.) It is reasonable to assume that these items will be included in any subsequent rule development governing RLV O&M.

In many cases, however, the lesson or issue being evaluated is less clearly defined and sufficient experience or research is not available to validate the lesson or issue. Others are technology dependent and only apply to a narrow set of RLV concepts. For these cases, Guideline Input Considerations (GICs) have been developed and the term "should" is used. These GICs are numbered sequentially with a Maintenance Function prefix (e.g., the first Perform Maintenance Guideline Input Consideration is numbered Perf Gen Maint GIC-1.) While these GICs are candidates for inclusion in any subsequent rulemaking, it is reasonable to assume that further work may be necessary.

Please note that there are many additional safety issues that an RLV Operator should consider for the safety of maintainers and technicians; FAA/AST is only currently charged with public safety concerns. Further, no delineation of when and how rules would be applied is made in these considerations. Some guidelines may be considered during the licensing stage while others may be considered as repeated launches are executed for the same RLV under a specific launch license.

Within the following sections, Occupational Safety and Health Administration (OSHA) appears in many of the Inter/Intra Agency Considerations subsections. Although OSHA is concerned with worker safety and not the general public, the authors of this document believe that jurisdictional issues should be addressed for cases where a worker safety situation may escalate into a public safety concern.

1.3.2 Suggestion Form

It should be noted that these Guideline Inputs are expected to evolve as the industry matures and additional data becomes available, either from research or through actual flight activity. The reader is encouraged to share their experiences and knowledge through use of the Suggestion Form in Appendix B: RLV Guideline Input Suggestion Form. It is the FAA's intent to periodically review these Guideline Inputs to ensure they are current, particularly with respect to issues that are technology dependent.

1.4 Relationship to RLV Licensing

The impetus for this effort was to provide a common set of criteria related to O&M that could be used by FAA/AST to evaluate RLV developer/operator license applications. The Guideline Inputs and the related Guideline Input Considerations contained in this volume are focused on RLV maintenance with particular emphasis placed on issues unique to the function being addressed and failure to follow these guidelines could pose a risk to the public. RLV developer/operators are expected to explain how each Guideline is satisfied for their particular vehicle design or CONOPS.

In a previous tasking, the RTI team proposed a formal set of readiness reviews, one for operations and one for maintenance. In addition, the concept of Instructions for Continued Flight-worthiness (ICF) and an Operations or Flight Manual was introduced. The reviews were intended to be focused activities within the context of the overall mission readiness review required by the RLV licensing rule. The Operations Manual was designed to lend form to the mission operational requirements. The ICF filled a gap in the current licensing description by addressing those considerations for the turnaround of an RLV and preparation for subsequent flights. The FAA has adopted the term Maintenance Program Plan (MPP) in place of ICF. Additionally, RTI proposes that the FAA also incorporate the requirement for the RLV Operator to develop and utilize an approved Maintenance Manual. The Maintenance Program Plan is considered by RTI to be similar in scope and breadth to the CONOPS document.

RTI believes that to further clarify the licensing rule and to better align with the proposed guideline structure, two additional data items should be provided to AST by the RLV developer/operator for review. These two items are a Training Manual and an Approval Manual. Note that this data can be packaged as part of the Operations Manual, Maintenance Manual, in a combined document, or individual documents, if the license applicant so chooses, provided that the data is clearly identified. The four documents, taken together, will allow individual RLV developer/operators to address FAA/AST Guidelines. At the same time, the use of a common set of manuals will help FAA/AST evaluate the appropriateness and completeness of the provided data in a uniform manner.

1.5 Subsystem and Functional Context

Functional Guideline Inputs have been developed for those activities associated with operations and maintenance, as well as the related areas of training and approval. Figure 1 illustrates how these four areas relate to one another and where they fit in the broader scope of RLV licensing, approvals, and RLV development. It should be noted this effort considers only the items to the right of the vertical line in Figure 1. This relationship is highlighted in Figure 2.

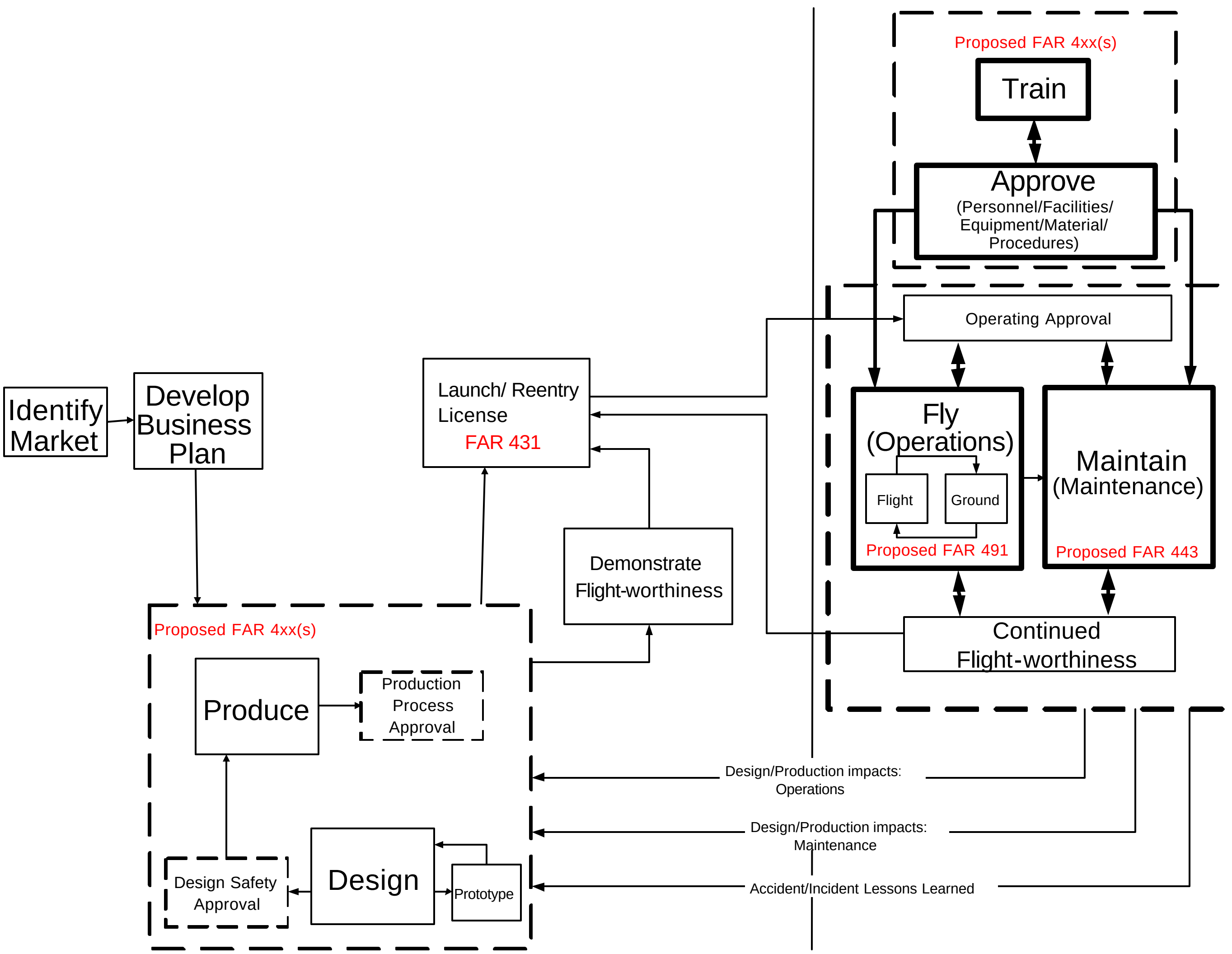

Figure 1 RLV Context Diagram

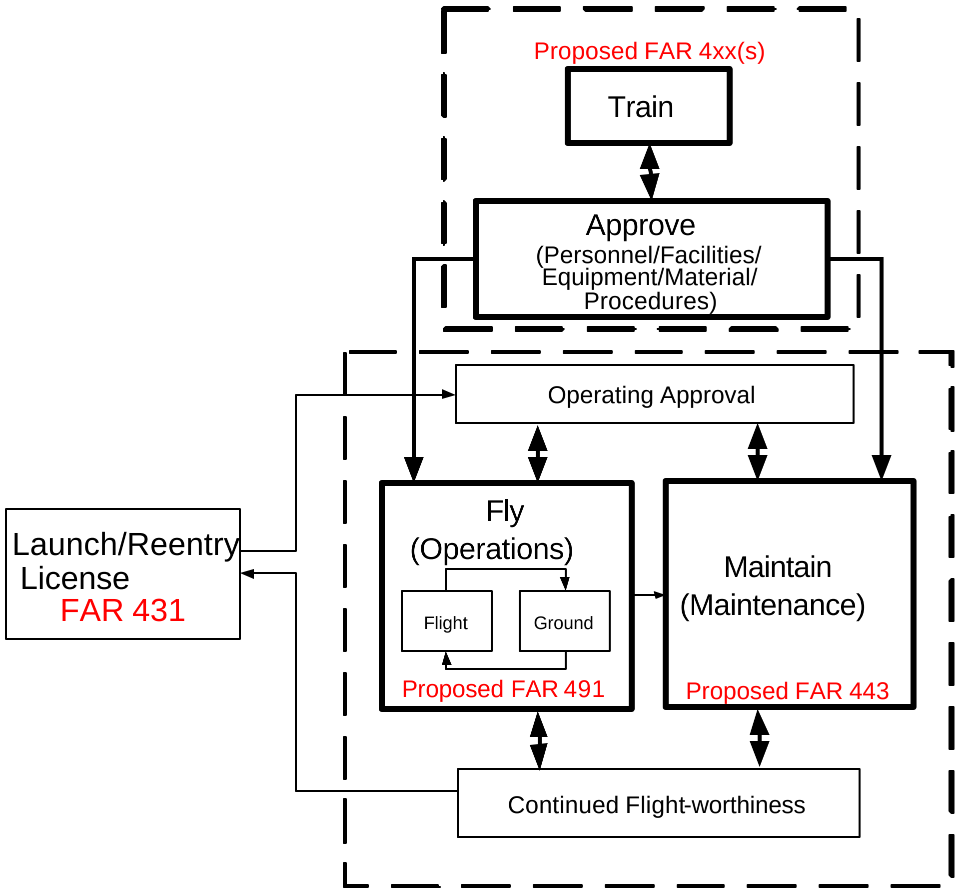

Figure 2 RLV O&M Context

It should also be noted that this top-down analysis is being supplemented by a bottom-up analysis effort being conducted by the FAA. The two efforts taken together are intended to serve as the basis for guidance development in the area of RLV O&M, see Figure 3.

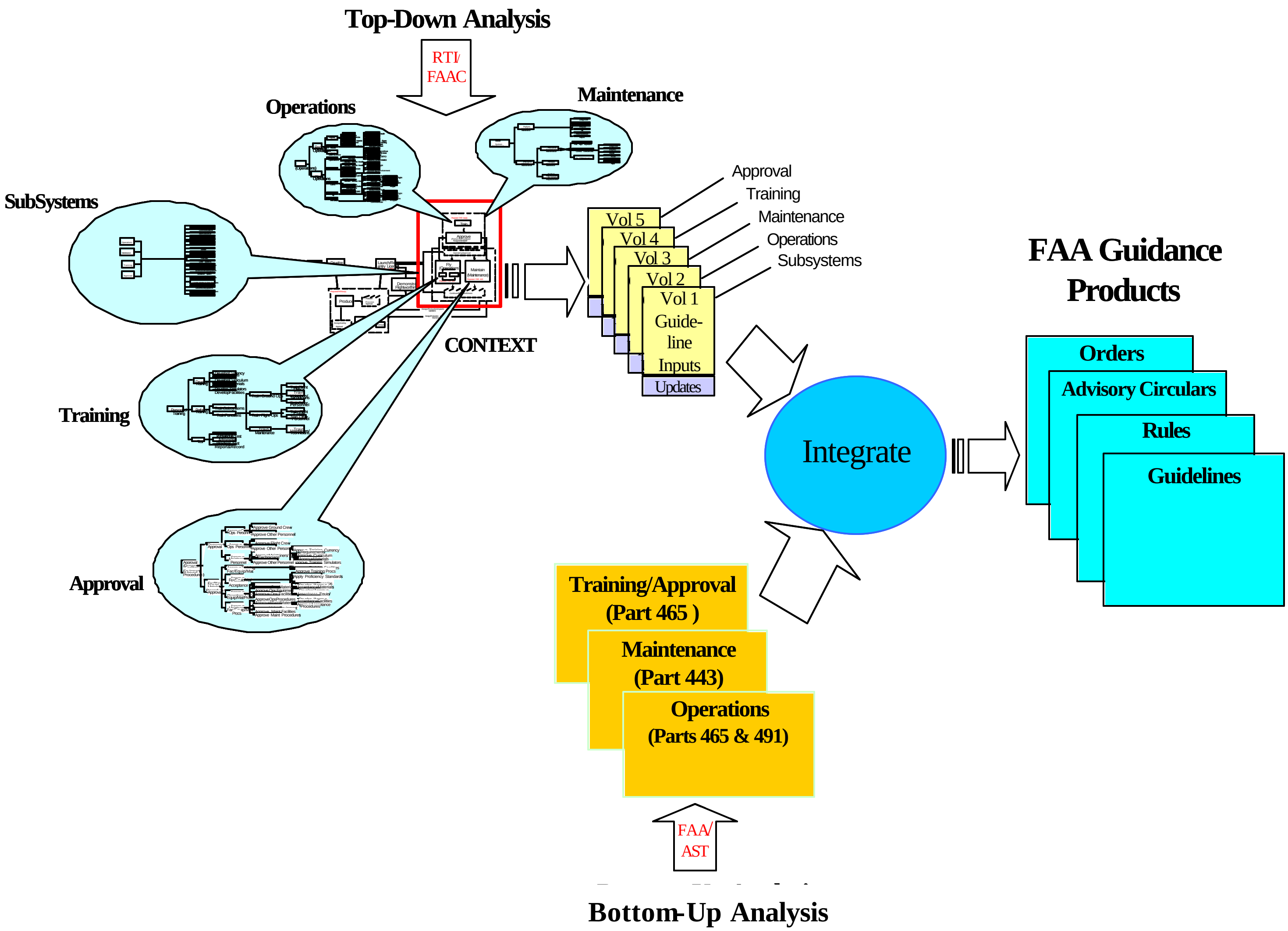

Figure 3 Guidance Document Process

As shown in Figure 3, the ultimate product of this activity is expected to be one or more guidance documents from the FAA. The FAA has realized that given the current level of maturity within the commercial RLV industry, the best approach to take in the near-term is the production of guidelines that can be employed by both the FAA and industry to evaluate proposed RLV's O&M activities on public safety. With this in mind, the top-down analysis has been organized around a 'divide and conquer' approach where individual subsystems and functions are examined for their potential contribution to public safety.

The following sections describe each top-level function and major sub-functions; provide definitions for each function and sub-functions; and provides a brief treatment of the major public-safety considerations for each function. It should be noted that the functions depicted and discussed are presented in terms of an action, hence the term "function". This is in contrast to the subsystems that are addressed in Subsystems-Volume 1 of this document, which are hardware related.

2.0 Maintenance Decomposition

Figure 4 provides a functional decomposition for RLV maintenance as developed in this tasking. Utilizing the aviation model for maintenance contained in MSG-3, the Maintenance Function was broken into three major sub-functions, Perform General Maintenance, Perform Unscheduled Maintenance, and Perform Scheduled Maintenance activities. The sub-functions include necessary maintenance tasks that are common to any RLV, Ground Support Equipment (GSE), and Facility; preparation of the RLV for its next flight; any interval-driven maintenance; and finally any condition-based maintenance for the RLV, GSE, or Facility. The RLV Operator shall plan all of these activities as early as possible in the pre-application process in the form of a Maintenance Program Plan. The FAA/AST shall review the plan for its relevance to the specific RLV, for completeness and how it satisfies FAA requirements and criteria.

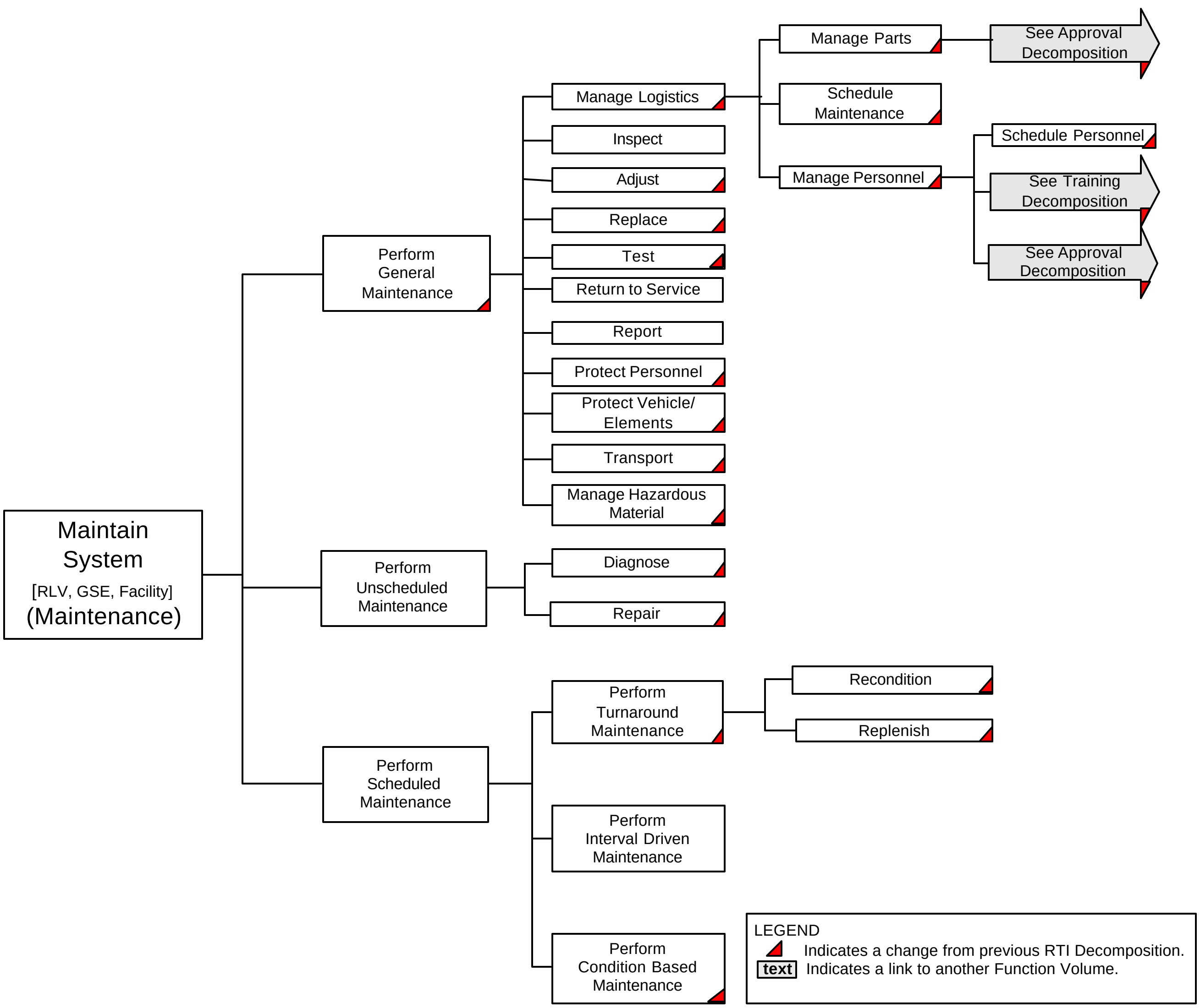

Figure 4 Maintenance Functional Decomposition

The results of the CFR reviews, as well as the data collected during previous efforts, were used as a starting point for deriving these functions. RTI then collected and analyzed several references to further characterize maintenance. Previous work presented the first functional decomposition of RLV Maintenance Functions. These maintenance functions and sub-functions have been further analyzed and refined here in this effort for maintenance. While many functions remain the same, there are several new sub-functions and function reorganizations. See Appendix C: Traceability of Maintenance Function Decomposition for function and sub-function traceability from the previous Maintenance Decomposition to the current Maintenance Decomposition as reflected in Figure 4.

3.0 General Maintenance Guideline Recommendations

The following Guideline Inputs (GIs) were developed to reflect those tasks or procedures that are general in nature and apply to RLV Maintenance.

General Maint GI - 1. RLV Operator Maintenance Program Plan

Guideline Input

RLV Operators shall develop a Maintenance Program Plan for each vehicle type.

Rationale

To account for the differences in RLV designs, each RLV Operator must provide a Maintenance Program Plan that describes the operator's intent and/or assumptions relative to RLV maintenance. This plan will include general strategies associated with both unscheduled and scheduled maintenance for the RLV vehicle type, and its associated Ground Support Equipment (GSE) and facilities. The Maintenance Program Plan is complementary to the RLV Operator's Concept of Operations Document.

Although the Maintenance Program Plan will be implemented through a procedural Maintenance Manual, the Maintenance Program Plan's value to the FAA lies in the additional clarity of purpose it will provide. Specifically, it will highlight to the FAA general assumptions/intent that may affect public safety; and it will provide the FAA with necessary insight into the following items of interest:

1. How the RLV maintenance program will ensure general public safety and limit/mitigate environmental hazard potentials.
2. What the differences will be between In-Line, Off-Line, and Depot Level Maintenance activities for different configurations of the RLV type.
3. How the RLV maintenance activities will be conducted at the launch and landing sites.
4. What inter/intra agency (both local and federal) coordination that may be required.
5. The logistical support that will be necessary for maintenance of the RLV and its associated GSE/ facilities.
6. Configuration management program for hardware, software and documentation.
7. Human Error Management Programs[3], that addresses the following:
   a) Who will oversee/administer the program?
   b) How will errors be investigated?
   c) How will investigation results be validated?
   d) How will error data be tracked and analyzed?
   e) How will prevention/intervention strategies be implemented to prevent errors from occurring/recurring?
   f) How will results of the program be measured?

General Maint GI - 2. Maintenance Manual

Guideline Input

RLV Operators shall develop an FAA-approved vehicle-specific Maintenance Manual.

Rationale

Since many RLV concepts include ground-breaking/novel technologies, there is minimal commonality between current industry maintenance procedures and those required for specific RLV maintenance procedures. This lack of commonality hinders the development of common technology-specific maintenance approval/certification guidelines; therefore, each RLV Operator will need to develop a vehicle-specific Maintenance Manual and provide it to FAA/AST for approval.

This manual will provide the maintenance specifications and procedures associated with the specific RLV type for all configurations outlined in the Maintenance Program Plan. Additionally, the Maintenance Manual will contain the nominal and off-nominal maintenance procedures for the FAA-approved RLV design.

Minimally, the following items for conducting general, scheduled and unscheduled maintenance should be included in the Maintenance Manual:

1. List of safety critical RLV and GSE/Facilities sub-systems and their maintenance requirements and procedures
2. Schedule for interval-driven maintenance (i.e. Scheduled Maintenance)
3. Subsystem/system maintenance procedures
4. Hazardous material types and handling procedures
5. Engine/motor refurbishment and reconditioning procedures
6. Checklists for normal and contingency maintenance procedures
7. Reporting process to include lessons-learned
8. Personnel Requirements
9. Tools/Test Equipment identification, description, and calibration requirements.

General Maint GI - 3. Maintenance Hazard Analysis and Mitigation Planning

Guideline Input

An RLV Operator shall perform a hazard analysis and develop appropriate mitigation procedures for those maintenance activities that may cause an unacceptable risk to the public.

Rationale

RLV maintenance activities must be assessed to determine specific processes/procedures that require hazard analysis/mitigation. The following is a candidate list for hazard analysis:

1. Chemical or physical (pressure) reactions between hardware elements
2. Collisions during handling
3. Exposure to environmental elements such as lightning and/or thermal conditions that may cause explosive hazards
4. Environmental hazards such as hazardous fluid spills
5. Gas plumes

Hazard analyses ascertain the potential repercussions for a plausible mishap/malfunction. Once the hazard/repercussion is understood, a mitigation action must be developed.

The mitigation action may be the development/modification of maintenance procedures that, by default, completely neutralize the hazard (e.g., limiting access to hazardous areas). Alternatively, a mitigation action/procedure may only reduce the potential for injuries or death due to mishaps/malfunctions to an "acceptable" level.

It is the responsibility of the Launch Operator to identify the hazards that could effect public safety and perform the necessary analysis that ensures proper mitigation of risk.

General Maint GI - 4. Maintenance Emergency Response Procedures

Guideline Input

A launch operator shall develop emergency response procedures for potential maintenance hazard sources.

Rationale

The ultimate purpose of the Maintenance Emergency Response part of the Emergency Response Plan (called out under the Operations Guidelines) is to ensure public safety in the event of a mishap during RLV, GSE, or Facility maintenance. Emergency response procedures (ERPs) are necessary to identify potential emergencies and the means to control, contain, and remove a hazard. ERPs will address handling requirements for hazardous materials, required personnel protection clothing/apparatus, and evacuation procedures for affected areas.

Maintenance activities must be assessed to determine appropriate emergency response procedures. The ERPs must specifically define the process for providing assistance to any injured people and describe the methods used to control any hazards associated with a mishap.

The overall Emergency Response Plan will describe the types of emergency support required, equipment to be used, emergency response personnel (their duties and qualifications), and any related agreements with any launch site operator and state, county, or local government agencies.

The following are a candidate set of functions that must be addressed in the ERP:

1. Firefighting
2. Explosive ordnance disposal
3. Chemical spill response
4. Medical support
5. Inadvertent release of radiological, corrosive, toxic, flammable, or cryogenic materials in hazardous quantities
6. Inadvertent activation of hazardous ordnance devices
7. Inadvertent ignition of flammable material
8. Inadvertent electrical shock/burns
9. Inadvertent deployment of appendages used in preparing the vehicle

General Maint GI - 5. Maintenance Statement of Compliance

Guideline Input

A Maintenance Statement of Compliance shall be submitted by the launch Operator to certify that each RLV will be maintained in accordance with the FAA-approved Maintenance Program Plan and Maintenance Manual for that specific vehicle design and configuration.

Rationale

Since RLV designs are markedly different, new, and novel; there is minimal commonality that can lead to technology specific approval guidelines. The referenced Maintenance Program Plan and Manual will contain the FAA-approved maintenance procedures and vehicle-unique limitations. The RLV Operator must maintain the vehicle in compliance with the Maintenance Program Plan and Manual to ensure maintenance is performed in a way that mitigates risk to the public.

General Maint GI - 6. Hazardous Substance Discharge

Guideline Input

If a discharge of a hazardous substance occurs during maintenance, a Hazardous Material Report (HMR) shall be filed with the EPA.

Rationale

In addition to the reporting requirements of the HMR found in Sections 171.15 and 171.16 of Title 49, a discharge of a hazardous substance is subject to EPA reporting requirements at 40 CFR 302.6 and may be subject to the reporting requirements of the U.S. Coast Guard at 33 CFR 153.203.[4]

General Maint GI - 7. Nonstandard Maintenance Procedures

Guideline Input

If maintenance methods, tools, or techniques to be used are other than what is specified in the Maintenance Manual, the RLV Operator shall prepare and submit a safety assessment to FAA that demonstrates that the deviation will not pose additional risk to public safety.

Rationale

Since RLV designs are new and novel, it is expected that maintenance procedures will evolve over time. Rather than requiring a complete resubmission of the Maintenance Manual, the FAA may approve changes to the Maintenance Manual in a structured, configuration-control-like method.

General Maint GI - 8. Safety Critical Software Failure Mitigation

Guideline Input

Software failure mitigation techniques/methodologies/procedures shall be considered as part of the RLV Maintenance Program Plan and Maintenance Manual.

Rationale

Given the immaturity of the RLV industry, it is likely that many vehicles will be flying in an experimental mode for some time. Numerous accidents have occurred as a result of unverified software being installed and flown on test aircraft. For example, on Feb 7, 2001, an Iberian Airbus crashed in Spain due to a flight control software error.[5]

Regression testing based on the original system acceptance/approval testing is an example of a mitigation method that may be employed after a maintenance-related software modification is performed.

4.0 Perform General Maintenance

The following sub-functions were developed to reflect those tasks or procedures that are general in nature and apply to the Perform General Maintenance activities. Table 1 highlights the general definitions for general maintenance sub-functions.

Table 1 Perform General Maintenance Definitions

<table>
<tr><td rowspan="12">Manage Logistics</td><td colspan="3">[Maintenance ? Perform General Maintenance ? Logistics]</td></tr>
<tr><td colspan="3">The Logistics Sub-function is the set of tasks, procedures, and activities to ensure the Maintenance Function is properly supplied, manned, and scheduled.</td></tr>
<tr><td rowspan="4">Manage Parts</td><td colspan="2">[Maintenance ? Perform General Maintenance ? Manage Logistics? Manage Parts]</td></tr>
<tr><td colspan="2">The Manage Parts Sub-function is the set of activities necessary to order, stock, and maintain proper quality and quantities of RLV/GSE/Facilities parts; including the required special part ordering and quality checks.</td></tr>
<tr><td rowspan="2">Approval Functional Decomposition</td><td>[Maintenance ? Perform General Maintenance ? Manage Logistics? Manage Parts? Approval Functional Decomposition]</td></tr>
<tr><td>The Approval Functional Decomposition outlines functions for performing approval activities associated with equipment, procedures, and personnel. See Volume 5, Approval, of this document.</td></tr>
<tr><td rowspan="2">Schedule Maintenance</td><td colspan="2">[Maintenance ? Perform General Maintenance ? Manage Logistics? Schedule Maintenance]</td></tr>
<tr><td colspan="2">The Schedule Maintenance Sub-function is the set of tasks and procedures to insert RLV/GSE/Facilities General, Unscheduled, Turnaround, Interval-driven, and Condition-Based Maintenance activities into the RLV Operator's overall activities schedule.</td></tr>
<tr><td rowspan="4">Manage Personnel</td><td colspan="2">[Maintenance ? Perform General Maintenance ? Manage Logistics? Manage Personnel]</td></tr>
<tr><td colspan="2">The Manage Personnel Sub-function is the set of tasks and procedures to ensure RLV/GSE/Facilities maintenance personnel are appropriately identified and tasked. This includes allowance for proper crew rest and ensuring that the personnel being scheduled are adequately trained and approved for the maintenance activities to be performed.</td></tr>
<tr><td rowspan="2">Schedule Personnel</td><td>[Maintenance ? Perform General Maintenance ? Manage Logistics? Manage Personnel? Schedule Personnel]</td></tr>
<tr><td>The Schedule Personnel Sub-function is the set of tasks and procedures to ensure RLV/GSE/Facilities maintenance personnel schedules reflect the personnel requirements associated with the maintenance task being scheduled: the personnel possess the appropriate skill levels and have been allotted the required crew rest.</td></tr>
</table>

		Training Functional Decomposition	*[Maintenance ? Perform General Maintenance ? Manage Logistics? Manage Personnel? Training Functional Decomposition]*
			The Training Functional Decomposition outlines functions for performing training of maintenance personnel. See Volume 4, Training, of this document.
		Approval Functional Decomposition	*[Maintenance ? Perform General Maintenance ? Manage Logistics? Manage Personnel? Approval Functional Decomposition]*
			The Approval Functional Decomposition outlines functions for performing approval activities associated with equipment, procedures, and personnel involved in maintenance activities. See Volume 5, Approval, of this document.
Inspect	*[Maintenance ? Perform General Maintenance ? Inspect]*		
	The Inspect Sub-function is the set of activities to check, test, or compare a system, sub-system, component, or part against established standards of operation, wear criteria (such as worn parts), and approved design.		
Adjust	*[Maintenance ? Perform General Maintenance ? Adjust]*		
	The Adjust Sub-function is the set of activities to return the sub-system or element to the original operational condition without replacement or repairing parts, components, or sub-systems.		
Replace	*[Maintenance ? Perform General Maintenance ? Replace]*		
	The Replace Sub-function is the set of activities to remove and replace a part, component, or sub-system with the same, or an approved equivalent, item to return the RLV to the original specifications.		
Test	*[Maintenance ? Perform General Maintenance ? Test]*		
	The Test Sub-function is the set of tasks/procedures used to evaluate the state of parts, components, or sub-systems to see whether these items meet approved operation criteria.		
Return to Service	*[Maintenance ? Perform General Maintenance ? Return to Service]*		
	The Return to Service Sub-function is the critical set of activities associated with the turnover from maintenance to operations. (e.g. when the RLV is declared flightworthy by maintenance or the GSE is declared “operational”).		
Report	*[Maintenance ? Perform General Maintenance ? Report]*		
	The Report Sub-function is the set of procedures to establish a formal record or summary of the performed maintenance activity.		
Protect Personnel	*[Maintenance ? Perform General Maintenance ? Protect Personnel]*		
	The Protect Personnel Sub-function includes those procedures and tasks necessary to ensure the safety of maintenance personnel. Potential risks include physical, chemical, and nuclear hazards.		
Protect Vehicle/Elements	*[Maintenance ? Perform General Maintenance ? Protect Vehicle/Elements]*		
	The Protect Vehicle/Elements Sub-function includes the procedures and tasks necessary to ensure RLV/GSE/Facilities are protected from unauthorized access, tampering, or damage (e.g., terrorist attacks).		
Transport	*[Maintenance ? Perform General Maintenance ? Transport]*		
	The Transport Sub-function includes the procedures and tasks for the movement of the RLV itself and any associated equipment, materials, cargo, or maintenance personnel to/from the maintenance activity areas.		
Manage Hazardous Material	*[Maintenance ? Perform General Maintenance ? Manage Hazardous Material]*		
	The Manage Hazardous Material Sub-function includes the procedures and tasks necessary for the safe storage, use, and loading/unloading of all hazardous material, other than propellants.		

4.1 General Discussion

The tasks, procedures, and sub-functions associated with the Perform General Maintenance sub-function are further explained in this section.

The following procedures and sub-functions are required to perform all types of maintenance:

1. Correlate parts, maintenance item, and personnel availability (Manage Logistics)
2. Inspecting the system or component (Inspect)
3. Performing maintenance adjustment work (Adjust)
4. Performing maintenance replacement work (Replace)
5. Testing the RLV/GSE/Facilities on which maintenance actions have occurred (Test)
6. Returning the item (vehicle, GSE or facility) to service (Return to Service)
7. Reporting maintenance activities, specific problems, and corrective actions (Report)
8. Preventing personnel hazards (Protect Personnel)
9. Preventing vehicle damage (Protect Vehicle/Elements)
10. Movement of the vehicle/elements and support equipment (Transport)
11. Preventing hazardous material mishaps (Manage Hazardous Material)

Logistics

Logistics includes the necessary tasks to ensure the availability of parts required to perform maintenance on the RLV and its associated GSE/Facilities; that maintenance tasks are appropriately scheduled in the RLV Operator's overall activities schedule; and that personnel scheduling meets the safety requirements of crew rest while still meeting mission and business requirements. Additionally, only personnel that have been trained on the specific RLV type, GSE, and/or Facilities will be utilized. Training and approval of these personnel are considered in the Training and Approval Volumes of this document; however, correlating the skill set of personnel to specific maintenance activities is part of the Logistics Sub-function.

RLV maintenance is assumed to closely parallel aircraft maintenance models due to the similarity in business models, anticipated frequency of flights, need for reduced turnaround time, and technologies involved. Specific practices for parts management will likely be similar to those found in the commercial and military aviation community. Additionally, the Space Shuttle may provide lessons learned for parts management for a large RLV and RLV program. For example,

> "The Space Shuttle has more than 4,000 replaceable parts, many provided by original manufacturers who are no longer in business. The NASA Shuttle Logistics Depot (NSLD), located near Kennedy

> Space Center (KSC), meets this challenge by manufacturing, overhauling, repairing and procuring all Shuttle Orbiter Line Replacement Units."[6]

The scheduling of the maintenance activities themselves must be part of the overall RLV Operator's daily program schedule to ensure timely corrective action in the event of a mishap or potentially hazardous situation and to ensure required preventive maintenance activities are performed.

The Manage Personnel Sub-function is the set of tasks and procedures that verify minimum maintenance-crew rest requirements are met and that the personnel assigned possess the appropriate skills. It is well known that both the aviation and space communities regulate the minimum crew rest required for pilots and on-board crewmembers. There is also a need to ensure that RLV Aerospace Maintenance Technicians (RAMTs) have adequate rest prior to performing safety critical tasks. Additionally, the skill level of the personnel must match the maintenance task. Both of these items will affect the specific maintenance personnel that will be assigned.

Inspect

Inspections will occur for RLV systems before the RLV is flown (pre-flight inspections), after the flight (post-flight inspections), and during/after hands-on maintenance activities. The pre-flight inspections consist of a set of checks/examinations designed to verify flight readiness of the vehicle, including closeout of problems identified in previous inspections and/or problem reports, and verification that all safety-critical equipment and systems are operational.

Post-flight inspections consist of a set of checks/tests designed to identify any unexpected problems or maintenance/repair items due to incidents during flight or due to exposure to conditions such as space environment, vibrations, high speed, etc. Post-flight inspection activities include checking, testing, or comparing a system, sub-system, component or part against established standards of operation, wear criteria (such as worn parts), and deviations from design.

In addition to inspecting the vehicle itself, maintenance technicians will inspect GSE and facilities as prescribed by the Maintenance Manual. For example, fluid lines in fuel carts and facility safety systems need to be inspected to ensure safe operations.

Adjust

Adjustments to the RLV's parts, components, or sub-systems, and GSE/facilities, may be necessary in any type of maintenance activity, scheduled or unscheduled. Adjustments will return the item to its original operational condition without any replacement or repairing, or may be subsequent to a replacement/repair task.

Replace

Replacement of a part, component, or sub-system may occur during any type of maintenance activity, scheduled or unscheduled. Although a replacement may deviate slightly from the original item, it must meet all specifications and tolerances of the original or the replacement must go through an approval process before being used as a maintenance item.

Test

The Test Sub-function is the set of tasks/procedures used to evaluate the state of parts, components, or sub-systems to ensure that these items meet approved operational criteria. The parts, components, or sub-systems being tested must demonstrate full operational capability within the margins specified in the Operations Manual and the Maintenance Manual in order to ensure proper operation of safety critical items.

Return to Service

The Return to Service Sub-function is the set of critical activities associated with the turnover from maintenance to operations crew. These activities will determine if the vehicle is "flightworthy" and the appropriate documentation of the vehicle's status will be generated. This sub-function is considered the point at which the RLV is "handed over" to the Operations Functions.

Additionally, this sub-function includes activities that will be performed to validate that the GSE and/or Facilities being maintained are available for operational use.

Report

The aviation domain provides a potential model for problem reporting called the Service Difficulty Program.

> "The objective of the Service Difficulty Reporting (SDR) Program is to achieve prompt and appropriate correction of conditions adversely affecting continued airworthiness of aeronautical products fleet wide. The SDR program is an exchange of information and a method of communication between the FAA and the aviation community concerning in-service problems. A report is filed whenever a system, component, or part of an aircraft, powerplant, propeller, or appliance fails to function in a normal or usual manner. In addition, if a system, component, or part of an aircraft, powerplant, propeller, or appliance has a flaw or imperfection which impairs, or which may impair its future function, it is considered defective and should be reported under the program. These reports are known by a variety of names: Service Difficulty Reports (SDR), Malfunction and Defect Reports (M and D) and Maintenance Difficulty Reports (MDR). The consolidation, collation, and analysis of the data and the rapid dissemination of trends, problems and alert information to the appropriate segments

> of the aviation community and FAA effectively and economically provides a method to ensure future aviation safety. The FAA analyzes SDR data for safety implications and reviews the data to identify possible trends that may not be apparent regionally or to individual operators. As a result of this review, the FAA may disseminate safety information to a particular section of the aviation community. The FAA also may adopt new regulations or issue airworthiness directives (AD's) to address a specific problem."[7]

The advantage of this program is that the FAA has immediate access to problem data for trending and regulatory analyses. The disadvantage of this approach, from an RLV Operator perspective, would be the potential increased overhead associated with problem reporting during maintenance management function.

Some lessons-learned from the Shuttle's Problem Reporting And Corrective Action (PRACA) system include the necessity for trend analysis on problem reports/failures/mishaps and "near misses". Additionally PRACA has highlighted the need for an integrated view of logistics activities, (e.g. parts management correlated with maintenance activities and problem reporting).

Protect Personnel

Ensuring the safety of maintenance personnel during maintenance of the RLV starts with the identification of hazardous/potentially-hazardous activities, followed by the appropriate procedure development and use of protective equipment. Personnel protection includes the maintenance personnel protection equipment (e.g., goggles, ear protectors, Self-Contained Atmospheric Protective Ensemble (SCAPE) suits), and the execution of procedures designed to mitigate risk during maintenance.

Protect Vehicle/Elements

The need to ensure the security of the RLV and its flight elements is two-fold. First, there is the general need for the RLV Operator to protect its assets. This clearly is not a public safety issue. Secondly, space transportation security in general is a high priority in the Homeland Security office. Through intelligence data, the launch industry (in particular the Space Shuttle) was identified as an Al Qaeda target.[8] This information, and the events of attacks on the United States that occurred on September 11, 2001, emphasize our nation's airports and launch sites as high-profile targets.

A five-page Homeland Security Department internal advisory memo recommended that aviation security officials increase security beyond existing security directives. The Transportation Security Administration issued emergency amendments to the directives. Existing directives focused on the passenger side of the airport where pre-gate security screening is done. Specifically, the memo advised officials to tighten ramp security, where the catering, cleaning, fueling, and maintenance of aircraft take place. As one of several additional protective measures the memo recommends, "Secure unattended aircraft to prevent unauthorized use".[9]

In addition to the concern for “unauthorized use” of an RLV, the “explosive potential” of an RLV may be of even greater concern to public safety. Thus, it is necessary to ensure only authorized personnel are near the vehicle while it is in a maintenance status.

Transport

Transport involves the movement of the integrated RLV, individual flight elements, cargo, propellants, and all other materials. Transportation is multi-modal (i.e. land, sea, or air). The Department Of Transportation (DOT) regulates and inspects the movement of hazardous materials along any of these transportation routes. For example, the DOT Federal Railroad Administration (DOT/FRA) inspects the following: piping, valves, and fittings; enclosures/protective housings; pressure relief devices; and safety systems for any hazardous material shipments. DOT also regulates proximity and isolation measures between chemicals that may react to produce hazardous materials if they are transported together.

Manage Hazardous Material

Hazardous material is generally defined as a substance or material in a quantity or form that may pose an unreasonable risk to health, safety, or property. 14 CFR Part 401.5 defines hazardous materials as those identified in 49 CFR 172.101.

In addition to the general handling of hazardous materials, this sub-function includes the removal, remediation, and disposal of hazardous materials, soils, debris, waste, etc., using personnel and equipment in such a way that will minimize endangerment to health, life, or property.

For working conditions and protective gear, OSHA guidelines are applicable for all handlers of hazardous material; EPA rules will address environmental issues; and HAZMAT rules govern transport of these materials. The National Fire Protection Association (NFPA) diamond is commonly used to communicate general hazard contents. These NFPA diamonds are commonly located inside the main entrance of buildings to inform occupants; on the outside of the main entrance door to inform emergency response workers; at the perimeter fence entrance to inform the general public, and on hazardous products themselves.

4.2 Guideline Input Considerations

The following Guideline Input Considerations (GICs) have been identified for the Perform General Maintenance Function:

Perf Gen Maint GIC - 1. Appropriate handling procedures should be employed (e.g. electrostatic discharge precautions for sensitive electronics work).

Perf Gen Maint GIC - 2. When parts for coolant circulation are replaced, ensure that the fabrication of the parts is adequate to ensure a leak-proof joint.

Perf Gen Maint GIC - 3. Test stand equipment connection and operation should be performed in such a way as to not cause damage or unsafe conditions to the propulsion system or any other vehicle system.

Perf Gen Maint GIC - 4. Precision instrumentation should be maintained with the use of calibrated instrumentation and tools during maintenance.

Perf Gen Maint GIC - 5. Any software or hardware tools used to maintain avionics, and which have the opportunity to introduce errors, should be evaluated for correct operation and calibrated where needed.

Perf Gen Maint GIC - 6. Flightworthiness verification should include:

a. Proper functioning of movable or "intelligent" structures affecting flight control
b. Integral TPS component integrity
c. Plume impingement area inspection

Perf Gen Maint GIC - 7. Maintenance procedures should facilitate the collection of data on subsystem/component/part performance from one flight to the next.

Perf Gen Maint GIC - 8. An RLV Operator's response to emergency conditions should mitigate compromise of public/ personnel safety.

Perf Gen Maint GIC - 9. Defective part/subsystem maintenance should minimize explosive potential.

Perf Gen Maint GIC - 10. Any potential chemical or physical (pressure) reactions between the RLV/ components/ payload/other materials and transport equipment should be assessed for potential public safety implications.

Perf Gen Maint GIC - 11. There should be in place a procedure/system to ensure tool accountability after maintenance.

4.2.1 Inter/Intra Agency Considerations

The following Perform General Maintenance Function inter/intra agency considerations were identified:

1. The procedures for handling hazardous materials during the Perform General Maintenance function should be performed similar to those accomplished during Conduct Ground Operations. Handling and transportation of hazardous materials are governed by DOT Hazardous Material regulations. Similar standards such as those from OSHA and DOT should be employed. A key consideration would be to determine if propellant residuals could be re-used or recycled to minimize propellant-waste generation.
2. Venting and disposal of hazardous materials should follow the Environmental Protection Agency (EPA) regulations for disposal of hazardous materials.
3. The North American Emergency Response Guidebook provides guidance on handling hazardous materials. It cross-references shipping names, UN numbers (United Nations Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labeling of Chemicals) and DOT labels with emergency response procedures. It is available from the U.S. Department of Transportation, Research and Special Programs Administration. Also, the Department of Transportation publishes a Hazardous Materials Table in Section 101 of Part 172, Title 49 of the Code of Federal Regulations. These references should be reviewed and employed where applicable.
4. DOT coordination should occur with appropriate rail, air, and roadway transportation offices for safe practices and regulations associated with the transportation of hazardous materials on public routes.
5. Federal Communication Commission (FCC) coordination should occur for all frequency assignments used in RLV operations, particularly those employed in emergencies.
6. The Department of Defense Explosive Safety Board (ESB) should be consulted to provide a source of lessons learned to FAA/AST for conducting RLV safety evaluations, storage of propellants, and chemical agents.[10]
7. National Fire Protection Association (NFPA) coordination should be required to ensure that adequate fire safety and mitigation procedures are in place for launch/takeoff preparations.

4.3 Guideline Recommendations

Perf Gen Maint GI - 1. Configuration Management

Guideline Input

The RLV Operator shall develop procedures that follow industry standard configuration management practices/procedures for the RLV/GSE/Facilities.

Rationale

By employing tight configuration control procedures, the RLV Operator will ensure that the RLV and its associated GSE/Facilities are used only in their "approved" state.

If maintenance activities were allowed to change the configuration of RLV/GSE/Facilities, the safety analyses used in the design safety process or licensing determination could be rendered invalid and the safety factors/measures that were integral to approval or determination process may be inadvertently compromised.

Examples of procedures that may be used to monitor configuration status include:

1. Post maintenance tests to verify flightworthiness of the vehicle must ensure no change to the configuration has occurred during maintenance.
2. Periodic inspection of processing facilities to ensure proper configuration is being maintained. In particular, cryogenics, vacuum systems, and thermal control systems all have serious potential safety risks if configured or assembled incorrectly.
3. Industry standard software configuration management systems should be employed. Software configuration errors have been linked to both aviation and space industry incidents. For example, a configuration management problem involving a navigation computer was implicated in the Antarctica crash of the Air New Zealand plane into Mount Erebus.[11]

Perf Gen Maint GI - 2. Minimum Turnaround Inspection List

Guideline Input

The RLV Operator shall develop and use a Minimum Turnaround Inspection List for use during turnaround maintenance.

Rationale

A minimum inspection list will ensure critical subsystems, components, and parts will be inspected prior to next flight. The following is a list of candidate major component areas for inspection, if applicable to the RLV type:

1. Wings
2. Rocket Motors and/or Engines
3. Flight Compartment/Cabin
4. Environmental Control & Life Support Systems
5. Landing Gear
6. Aft Fuselage/Empennage
7. Leak checks
8. Shut-off-valves
9. Water/contaminant protection components
10. Pressure and temperature regulators
11. Anti-skid brake inspections including electrical power/pedal calibration integrity related hydraulics
12. Autonomous landing equipment for proper arming and connectivity with other on-board systems (e.g., electrical) following maintenance
13. Tire wear due to braking. Note: may reduce strength of tire structure resulting in rupture
14. Hydraulic fluid leakage. Note: hydraulic fluid in the hot wheel well area may ignite and cause RLV damage, personnel injury and risk to public safety
15. Thermal Protection System
16. Avionics
17. Control Surfaces
18. Communications Equipment

Note: Water and other contaminants are the principal cause of failure, wear and the improper operation of pneumatic equipment such as: air compressors, air filters, separators, dryers and compressed air handling system drop legs.[12]

Perf Gen Maint GI - 3. Flight Safety System (FSS) Flight Control Testing

Guideline Input

Maintenance testing shall verify that the FSS is capable of controlling the RLV (if so designed) and is operationally ready.

Rationale

If the RLV is designed such that the FSS is capable of controlling the vehicle even if the vehicle is not controllable by the flight crew, then testing of this capability should occur prior to turnover to operational status to ensure public safety.

Perf Gen Maint GI - 4. Part Replacement Criteria

Guideline Input

Replacement parts shall have the exact functional material and structure characteristics as the original design.

Rationale

When exact part replacement is not possible, the replacement part must only be accepted after proper characteristic tests are conducted. The examination of the following characteristics must ensure the replacement part to be the same or superior to the design material:

1. Conductivity
2. Ductility
3. Thermal expansion
4. Pressure tolerances
5. Fracture toughness
6. Core perforation
7. Water absorbency / repellency
8. Thermal coating or other surface enhancements
9. Structural properties and load bearing properties if molded structural TPS is used
10. Weight/density properties which will affect vehicle weight calculations
11. Bonding/chemical reaction issues especially in space conditions
12. Fatigue life
13. Vibration
14. Charged particle tolerances (especially for printed circuit boards and complex electronic hardware),

Changes in technology/materials from part manufacturers shall be monitored by the RLV maintainers. Technology or material introduced during parts replacement that are not conducive to the space environment may result in unsafe operating conditions. If there are deviations from the FAA-approved parts for safety critical systems, the RLV Operator must solicit FAA approval prior to installing the new part.

Perf Gen Maint GI - 5. Communication of Maintenance Status/Tracking

Guideline Input

Opened maintenance items, their status and disposition, and their associated criticality (e.g. safety critical system) shall be conveyed by the RLV Operator to the FAA, maintenance personnel, and flight/ground operations personnel, prior to next flight.

Rationale

Communication of maintenance status/tracking information to the FAA will ensure that during this trend establishment period for RLV programs, "unexpected" anomalies are identified and tracked, and system/subsystem reliability information will be gathered.

Communication between maintenance and operations teams will help ensure that operator error is tracked and corrected for to be determined maintenance items. Additionally, operations personnel may have input that effects trend analyses.

Perf Gen Maint GI - 6. Maintenance Procedures Update

Guideline Input

Maintenance procedures shall be updated and modified based on trend analysis.

Rationale

When trend analysis identifies anomalies that are repeatedly found, maintenance procedures must be updated to include checks for them as a standard maintenance task. Occurrence of these anomalies may also be critical to the continued flightworthiness of the vehicle.

Perf Gen Maint GI - 7. Wiring Inspection Procedures

Guideline Input

The RLV Operator shall develop wiring inspection procedures/techniques that maximize inspection of all vehicle wiring in a non-destructive manner.

Rationale

While not directly indicted as a cause of the Columbia accident, the Columbia Accident Investigation Board noted that wiring issues were a significant risk item for the Shuttle.[13]

Additionally, the TWA Flight 800 (July 1996) and Swissair Flight 111 (September 1998) accidents led to heightened concerns about the safety of non-structural aircraft systems, including wiring. Since these accidents, FAA has issued over 40 Airworthiness Directives focusing on wiring. [14]

As part of their research, the FAA and industry completed non-intrusive (or visual) inspections of wiring in 81 in-service aircraft. Many of the noted problems involved improper clamping and routing of wire; cracked and abraded insulation; exposed conductors; and problems with previous repairs. Additionally, the majority of discrepancies with wire were found in areas of frequent maintenance activity.[14]

Recognizing the importance of the issue, the White House created a new interagency Wire Safety Working Group in the year 2000 to coordinate research on the safety of aging wiring in aircraft, Space Shuttles, and nuclear power plants.[14]

Perf Gen Maint GI - 8. Hazardous Materials Handling During Maintenance

Guideline Input

The RLV Operator shall develop and use procedures for handling hazardous materials that comply with federal, state, and local regulations and laws.

Rationale

Hazard protections associated with the operation of GSE and facilities will comply with local spaceport or spaceport operator directives and specific Federal guidelines such as Occupational Safety and Health Administration (OSHA), Department Of Transportation, and Environmental Protection Agency. These federal guidelines and industry standards should be specified as compliance documents.

Hazardous materials handling should ensure there is neither generation of hazardous waste nor release of air and water pollutants.

Additionally, new materials and chemicals that are introduced may not be listed in any of the traditional standards or guidelines. Since these new materials and chemicals may pose a risk to the public and/or generate hazardous waste in the form of air and water pollutants, the RLV Operator must show compliance with the intent of federal, state, and local laws, standards, and guidelines.

These procedures will be incorporated into the Maintenance Manual.

Perf Gen Maint GI - 9. Personnel Protection During Hazardous Maintenance

Guideline Input

The RLV maintenance personnel shall comply with local state, Occupational Safety and Health Administration (OSHA), Department Of Transportation, and Environmental Protection Agency guidelines, and the RLV Operator Maintenance Manual during the performance of hazardous operations.

Rationale

This requirement is to ensure that maintenance personnel are protected during hazardous maintenance activities so as not to have a negative effect on public safety in two ways:

1. Should one of these individuals be incapacitated during a hazardous maintenance activity, their ability to perform contingency procedures during an accident could be compromised.
2. Should they become incapacitated during the performance of a safety critical procedure, they could cause an accident with public safety implications.

Perf Gen Maint GI - 10. Maintain, Test, and Checkout Communications Subsystem

Guideline Input

Maintainer/technicians shall maintain, test, and checkout the Communications Subsystem following any maintenance/repair action.

Rationale

Given the importance of the communications subsystem, maintainers must be proficient in their tasks to not only diagnose/repair/restore the equipment, but also to operationally test the communications subsystem to ensure no problems were introduced during maintenance task.

Maintainers will have the ability to:

1. Assess the correctness of the communication display data and format
2. Assess error messages
3. Perform corrective actions recommended in the manuals as well as on the displays
4. Use transmitters, receivers, and antennae
5. Perform link analysis
6. Perform end-to-end testing

Perf Gen Maint GI - 11. Navigation/Guidance Sensor Calibration

Guideline Input

Following any navigation/guidance subsystem maintenance actions, all navigation/guidance subsystem sensors shall be recalibrated in accordance with the Maintenance Manual.

Rationale

Accurate position/velocity/attitude data is imperative to developing correct flight control commands. In order to minimize the chance of sensor inaccuracies propagating to flight control commands, the sensors must be recalibrated whenever any maintenance/repair activities may have directly or indirectly affected their alignment.

Incorrect flight control commands could impact both Air Traffic Management and create the potential for object collision (e.g., COLA and COMBO).

Perf Gen Maint GI - 12. Flight Control Post Maintenance Inspection and Testing

Guideline Input

Flight Control Subsystems shall undergo a post-maintenance inspection and testing following any maintenance on wiring or physical interconnections, to verify proper operation.

Rationale

Incorrect reconnection of flight control components has been the root cause of many commercial and military aircraft crashes. Often such errors have led to flight controls acting in an opposite fashion to the original design and opposite of what the pilot is expecting.

Perf Gen Maint GI - 13. Wiring Harness Integrity

Guideline Input

If string bindings or cable ties are removed during maintenance/repair activities, maintenance procedures and inspection checklists shall ensure that such items are replaced in accordance with schematic/structural drawings and specifications.

Rationale

The structural integrity of the wiring harness depends on these bindings/ties. If a wiring harness does not provide sufficient support to the wires, their insulation may crack/chafe and a short circuit could result.

This was illustrated in the grounding of the Space Shuttle fleet in 1999, where an exposed wire caused a short circuit that took two engine computers off-line.[15]

Perf Gen Maint GI - 14. Safety Critical Software Assurance

Guideline Input

RLV launch control software and vehicle health and management software shall be required to undergo a Software Conformity Inspection after any maintenance/repair actions to the software programs.

Rationale

Latent software errors have been the source of catastrophic space mission failures, and have been similarly indicted in a number of aviation accidents:

1. On June 4, 1996, the first flight of the European Space Agency's new Ariane 5 rocket failed shortly after launching, resulting in an estimated uninsured loss of a half billion dollars. It was reportedly due to the lack of exception handling of a floating-point error in a conversion from a 64-bit integer to a 16-bit signed integer.[16]
2. In April of 1999 a software bug caused the failure of a $1.2 billion U.S. military satellite launch, the costliest unmanned accident in the history of Cape Canaveral launches. [17]
3. On August 5, 1997, a Korean Air jet crashed in Guam. A radar system that could have warned the aircraft that it was flying too low was hobbled by a software error.[18]

Software conformity assessment provides objective evidence that a product meets standards of safety.[19] Generally, conformity assessments ensure that the software, and any modification, is managed under a stringent configuration management process.

Perf Gen Maint GI - 15. Tracking and Surveillance System Maintenance

Guideline Input

Onboard tracking and surveillance capability shall be maintained in accordance with an approved Maintenance Manual and the test to Return to Service shall be integrated with a Flight Safety Subsystem test.

Rationale

Given the safety-critical nature of tracking and surveillance systems and its importance in protecting public safety, the system must operate correctly during all phases of flight.

The close connection, between Flight Safety Subsystem (FSS) and the tracking and surveillance subsystem, implies that any changes made to tracking and surveillance components could affect the FSS. Therefore, an integrated test must be performed in order to ensure the FSS is functioning correctly and is operationally ready for flight.

Perf Gen Maint GI - 16. Propellant Management Safety

Guideline Input

Propellant management shall be conducted so as not to pose a safety risk to the public during maintenance activities.

Rationale

Propellant subsystem maintenance procedures should take into consideration the risk to public safety and include specific risk mitigation steps to be performed during the maintenance activity. An example of procedural mitigation is the imposition of serial loading of hypergolic propellants so as to minimize the explosive potential due to inadvertent contact.

Some additional issues that may need to be addressed are:

1. Propellant contamination avoidance
2. Valve seating
3. Cryogenic boil-off
4. Liquid jet impingement on diffusers

Perf Gen Maint GI - 17. Inspection of Hydraulics

Guideline Input

The RLV hydraulic subsystem shall be inspected during scheduled and unscheduled maintenance activities to ensure the integrity of the hydraulic subsystem.

Rationale

Leaks in the hydraulic subsystem may result in contamination of the surrounding area with hydraulic fluid and/or failure of hydraulic components.

Hydraulic systems are inspected for leakage, worn or damaged tubing, worn or damaged hoses, wear of moving parts, security of mounting for all units, and any other condition specified by the Maintenance Manual. A complete inspection includes considering the age, cure date, stiffness of the hose, and an operational check of all subsystems.

Perf Gen Maint GI - 18. Inspection of Pneumatics Subsystem

Guideline Input

The RLV pneumatics subsystem shall be inspected during scheduled and unscheduled maintenance activities to ensure the integrity of the pneumatic subsystem.

Rationale

The proper and successful functioning of the pneumatics subsystem requires that the pressure on the fluid remains relatively constant. Any leaks in the subsystem will compromise this condition.

Pneumatic subsystems are inspected for leakage, worn or damaged tubing, worn or damaged hoses, wear of moving parts, security of mounting for all units, and any other condition specified by the maintenance manual. A complete inspection includes considering the age, cure date, stiffness of the hose, and an operational check of all subsystems.

Note: the National Transportation Safety Board has reported pneumatic system failures as a factor in an average of two fatal aviation accidents per year over the past ten years.[20]

Perf Gen Maint GI - 19. Operational Safety of Landing and Recovery

Guideline Input

If landing gear is used, maintenance procedures shall comply with the Maintenance Manual's specifications for limiting factors during specific test techniques.

Rationale

Non-destructive testing and inspections of critical use components must be employed. For example, detection of debris embedded in tires may require x-rays. Cracks in landing gear materials, in many cases, are not perceptible with the human eye and can only be detected by rigorous inspection techniques such as Eddy Current inspection. (Note: this nondestructive testing technique is only applicable to certain materials based on their conductivity and permeability.)

Perf Gen Maint GI - 20. Corrosion Control Requirements

Guideline Input

Maintenance of any metal-based facilities shall include corrosion control measures.

Rationale

Corrosion on these facilities will not only impact the structural integrity of the facility, it may also cause an explosion due to the interaction of the metal/rust with the propellants on-board the RLV.

5.0 Perform Unscheduled Maintenance

The following sub-functions were developed to reflect those tasks or procedures that are applicable to RLV Unscheduled Maintenance activities. Table 2 highlights the general definitions for unscheduled maintenance sub-functions.

Table 2 Perform Unscheduled Maintenance Definitions

Diagnose	*[Maintenance ? Perform Unscheduled Maintenance?Diagnose]* The Diagnose sub-function is the set of activities that are used to analyze the cause or nature of a faulty or anomalous condition. This may include the time and resources required to perform the action.
Repair	*[Maintenance ? Perform Unscheduled Maintenance?Repair]* The Repair sub-function is the set of activities to restore the RLV to continued flightworthiness-operating state by fixing a system, subsystem, component, or part.

5.1 General Discussion

The Perform Unscheduled Maintenance consists of the tasks, procedures, and sub-functions to correct discrepancies, or problems, that were identified during normal operation, scheduled maintenance, other unscheduled maintenance, or trend data analyses. The tasks and procedures performed during unscheduled maintenance that are common to all types of maintenance are addressed in Section 4.0 of this document. Only those sub-functions considered unique to Perform Unscheduled Maintenance are presented in this section.

Sources of unscheduled maintenance are varied and may include problems in system/component design, system/component failure or damage. In this sub-function, a system can be either hardware or software associated with the RLV, GSE or facilities.

Diagnose

After the identification of a problem through inspection or, potentially, an automated systems report (e.g. the vehicle health and monitoring subsystem), the problem must then be diagnosed to determine its root cause. There are various techniques and technologies that are employed in the aviation community for the Diagnose Sub-function. For instance, in diagnosing jet engine problems, an old technology called ferrography is used to run the aircraft's lubricating fluid through a magnetic device to separate out metal shavings and other ferrous engine debris.

Many new techniques and technologies will be developed to meet the challenges of diagnosing RLV problems. For instance, one study[21] concluded that:

> "New approaches are needed for subsurface inspection; the temperature history (maximum temperature reached during reentry) is the best warning indicator of potential future damage; and improved inspection technology is needed for reinforced carbon-carbon components (e.g. nose cone and wing leading edges) that are likely to be used on all future vehicles"

Repair

Webster's dictionary defines repair as "to fix, or to restore". Therefore, the repair of a sub-system, component, or part is always considered unscheduled. Repair maintenance activities must return the subsystem, component, or part to the original design specifications and tolerances.

Note: although "alteration" may be considered a repair, it is not treated as a "maintenance task" here because of the design impact and would be treated in the design approval process highlighted in Figure 1 of this document.

5.2 Guideline Input Considerations

The following Guideline Input Considerations (GICs) have been identified for the Conduct Unscheduled Maintenance Function:

Perf Un-Sched Maint GIC - 1. Diagnose should utilize calibrated equipment to ensure complete and accurate analysis.

Perf Un-Sched Maint GIC - 2. The on-board vehicle health monitor/ management system should be utilized when diagnosing RLV repairs.

Perf Un-Sched Maint GIC - 3. A logbook for repair and alteration activities should be maintained. This log should contain specific data on parts used for the repair activity.

5.2.1 Inter/Intra Agency Considerations

The following Conduct Unscheduled Maintenance Function inter/intra agency considerations were identified:

1. DOT coordination should occur with appropriate rail, air, and roadway transportation offices for safe practices and regulations associated with the transportation of hazardous materials on public routes.
2. Federal Communication Commission (FCC) coordination should occur for all frequency assignments used in RLV operations, particularly those employed in emergencies.
3. The Department of Defense Explosive Safety Board (ESB) should be consulted to provide a source of lessons learned for FAA/AST for conducting RLV safety evaluations, storage of propellants, and chemical agents.[22]
4. National Fire Protection Association (NFPA) coordination should be required for procedure development to ensure that fire safety and mitigation procedures are in place for launch/takeoff preparations.

5.3 Guideline Recommendations

Un-Sched Maint GI - 1. Safing the Vehicle During Diagnosis

Guideline Input

During the Diagnose Sub-function, the RLV Aerospace Maintenance Technician shall continuously evaluate the safety of the RLV/GSE/Facilities configuration based on the problem analysis, and implement additional safing actions as appropriate.

Rationale

Due to the uncertainties associated with the cause for unscheduled maintenance, the problem could cause an unanticipated/unsafe configuration state.

Un-Sched Maint GI - 2. Material Compliance

Guideline Input

The RLV Aerospace Maintenance Technician shall only use materials that have been approved for the RLV/GSE/Facilities under repair.

Rationale

In a repair situation, there may be a need to fabricate an item to accomplish the repair. A deviation from the approved material for that "part" may compromise the integrity of the maintenance item and thereby affect public safety.

For example, use of inappropriate materials could affect the fatigue properties of the item. And, according to National Transportation Safety Board data, 291 accidents have been associated with fatigue cracking.[23]

Un-Sched Maint GI - 3. Analysis Post- Repair

Guideline Input

As part of a repair closeout activity, the RLV Operator shall perform, and provide to the FAA, an analysis of the cause and impact of the problem/repair.

Rationale

This analysis will include assessing the impact of the problem/repair on the operating characteristics and limitations of the RLV, GSE, or Facility.

The RLV industry and the FAA will use this analysis to assess the effect that the problem/repair may have on continued use and/or flightworthiness of specific components/parts, and to ensure prompt and appropriate corrective action for conditions adversely affecting continued flightworthiness of widely-used RLV industry products (e.g. pressure vessel materials).

Un-Sched Maint GI - 4. Post Repair Return to Service Assessment

Guideline Input

The RLV Operator shall analyze the potential impact of a repair maintenance activity to operating characteristics and limitations of the RLV/GSE/Facilities, and incorporate the results of this analysis into the Return to Service criteria.

Rationale

Because of the unanticipated nature of repairs, a repair may directly, or indirectly, affect the operation of other subsystems, components or parts. Therefore, in preparation for the Return to Service maintenance activity, the RLV Operator must assess the potential impact of the repair to other subsystems in order to develop the Return to Service criteria.

This will be critical in verifying general flightworthiness of the vehicle.

6.0 Perform Scheduled Maintenance

The following sub-functions were developed to reflect those tasks or procedures that are applicable to RLV Scheduled Maintenance activities. Table 3 highlights the general definitions for scheduled maintenance functions.

Table 3 Perform Scheduled Maintenance Definitions

Perform Turnaround Maintenance		*[Maintenance ? Perform Scheduled Maintenance ? Perform Turnaround Maintenance]* The Perform Turnaround Maintenance sub-function is the set of maintenance sub-functions that are performed between flights in order to return the RLV to flightworthiness status.
	Recondition	*[Maintenance ? Perform Scheduled Maintenance ? Perform Turnaround Maintenance ? Recondition]* The Recondition sub-function consists of the set of tasks that are performed to return the RLV to its original operating condition, to include software and hardware items.
	Replenish	*[Maintenance ? Perform Scheduled Maintenance ? Perform Turnaround Maintenance ? Replenish]* The Replenish sub-function is the set of tasks and procedures to restock, reload, and/or refill expendable items on-board the RLV.
Perform Interval-driven Maintenance		*[Maintenance ? Perform Scheduled Maintenance ? Perform Interval-driven Maintenance]* The Perform Interval-driven Maintenance sub-function consists of the performance of all necessary sub-functions, tasks, and procedures for maintenance of the RLV/GSE/Facilities that is performed with a particular frequency.
Perform Condition-Based Maintenance		*[Maintenance ? Perform Scheduled Maintenance ? Perform Condition-Based Maintenance]* The Perform Condition-Based Maintenance sub-function consists of all necessary sub-functions, tasks, and procedures for RLV Maintenance that is scheduled based on the condition of a part, component, or subsystem.

6.1 General Discussion

Scheduled maintenance tasks may be based on calendar time, number of flight hours, or parametric values associated with the condition of a subsystem/component/part or cycle time. Cycle time dependent maintenance tasks (e.g. propellant subsystem inspection) are performed during turnaround maintenance. Interval-driven maintenance is solely time- based. Some examples would be: inspection and checkout of those systems/subsystems that are affected whether the vehicle is flying or not (e.g. corrosion control inspection); or a replacement based on the number of flight hours logged for a given sub-system, component or part. Condition-based maintenance is a relatively new maintenance model that has become more and more attractive as advancements in the integrated vehicle health monitoring field have occurred.

Although the goal of Scheduled Maintenance is to prevent deficiencies, if an unexpected anomaly is discovered during a scheduled maintenance task, then associated corrective actions will be considered unscheduled maintenance and communicated/tracked according to Unscheduled Maintenance Guidelines.
Generally, reliability-centered scheduled maintenance is recommended; however, it requires a relatively deep understanding of the selected subsystem's

failure modes and the consequences of that failure to determine the "schedule". Failure modes are equipment/component-specific failures that result in functional failure of a subsystem. Whatever method is used to develop the initial schedule outlined in the Maintenance Manual will need to be revised based on trend analyses performed following the RLV/GSE/Facility deployment.

Perform Turnaround Maintenance

There will be a set of standard maintenance tasks performed during Turnaround Maintenance that are based solely on cycle time (e.g. propulsion subsystem tasks).

The first task performed during the Turnaround Maintenance sub-function should be a post-flight inspection. This inspection will be performed right after the recover operation, and will include a set of checks/tests designed to identify any unexpected problems or maintenance/repair items.

Specifically, the goal is to check, test or compare a system, sub-system, component or part against established standards of operation, wear criteria (such as worn parts), deviations from design, and damage due to incidents during flight or due to exposure to conditions such as space environment, vibrations, high speed, etc. Any anomalies and associated corrective actions discovered during Turnaround Maintenance will be considered unscheduled maintenance and communicated/tracked according to Unscheduled Maintenance Guidelines.

Perform Interval-driven Maintenance

Interval-driven Maintenance may be based either on calendar time, number of hours used, or cycle time. For example, traditional aviation often uses flight hours for scheduling powerplant overhaul activities and landing gear are evaluated based on numbers of takeoff/landing (i.e. cycle time). Of note: in a Reliability Centered Maintenance (RCM) program the interval-driven maintenance scheme will be based on the reliability for the various components of the system or subsystem.

Interval-driven tasks may not be initiated until the initial task/inspection date occurs. Once initiated, interval-driven tasks will have a Repeat Interval (RI) associated with them. Again, this interval will be based on calendar time, flight hours, or cycle time[24].

Perform Condition-Based Maintenance

Condition-Based Maintenance (CBM) is defined as "Maintenance actions based on actual condition (objective evidence of need) obtained from in-situ, non-invasive tests, operating and condition measurement."[25]

If so equipped, an RLV's Integrated Vehicle Health Management/Monitor (IVHM) Subsystem will provide information on the part, component, or subsystem's condition. The IVHM will enable the condition to be assessed, analyzed, and diagnosed for insertion into the operations and maintenance schedules.

CBM is unique from the other maintenance types as follows:

1. "Operations have now been engaged and integrated into the maintenance equation by becoming responsible for recognizing and correcting the existence of an abnormal condition or stressor level.
2. Finding the root cause stressors (parameters outside the design envelope) responsible for the off-design condition is now the prime directive.
3. The maintenance task can be preplanned and streamlined to eliminate the brushfire urgency and huge parts inventories, and minimize the maintenance impact on production."[26]

Availability prediction and analysis is included in determining the Condition-Based Maintenance task schedule. Availability can be estimated for components, items, or units but overall spacecraft system or ground system availability estimation is based on the combinations and connectivity of the units within the system.

There are three types of availability measures. One is the inherent availability, and it is a function of the as-designed reliability and maintainability characteristics. Second is the achieved availability and it is a function of the total time spent in an operational state versus the total corrective maintenance time and the total preventive maintenance time. The third basic measure of availability is operational availability and it considers all repair and ancillary support time: corrective and preventive maintenance time, administrative delay time, and logistic support time. Operational availability is the most all-inclusive and should be used when determining the schedule for a subsystem.[27]

6.2 Guideline Input Considerations

The following Guideline Input Considerations (GICs) have been identified for the Conduct Scheduled Maintenance Function:

Perf Sched Maint GIC - 1.	Appropriate handling procedures should be employed (e.g. electrostatic discharge precautions for working on sensitive electronics).
Perf Sched Maint GIC - 2.	Maintenance cycles should be adjusted based on inspection data (i.e. more frequent maintenance for an increased incidence of problems found).
Perf Sched Maint GIC - 3.	The interval, as measured by the maintainer, may be different from the interval meant by

maintenance procedures. It should be clearly stated whether the actual flight hours are counted or whether calendar time is counted for this interval.

Perf Sched Maint GIC - 4. Maintenance activities should manage general OSHA requirements relative to occupational safety that may not cover safe practices for new materials, chemicals, and technology (safe maintenance practices) that affect public safety.

6.2.1 Inter/Intra Agency Considerations

The following Conduct Scheduled Maintenance Function inter/intra agency considerations were identified:

1. DOT coordination should occur with appropriate rail, air, and roadway transportation offices for safe practices and regulations associated with the transportation of hazardous materials on public routes.
2. Federal Communication Commission (FCC) coordination should occur for all frequency assignments used in RLV maintenance procedures, particularly those employed in emergencies.
3. The Department of Defense Explosive Safety Board (ESB) should be consulted to provide a source of lessons learned for FAA/AST for conducting RLV safety evaluations, storage of propellants, and chemical agents.[28]
4. National Fire Protection Association (NFPA) coordination should be required for procedure development to ensure that fire safety and mitigation procedures are in place for maintenance.

6.3 Guideline Recommendations

Sched Maint GI - 1.Turnaround Maintenance - Structural Inspection

Guideline Input

During Turnaround Maintenance, the RLV operator shall perform a structural inspection of any structure that affects the safety critical subsystems delineated in the Maintenance Manual.

Rationale

The Columbia Accident Investigation Board's final report[29] included the following recommendation: Maintenance procedures should (sic shall) be in place that allow for a complete structural inspection using non-destructive evaluation techniques.

The RLV Structure Subsystem will be subjected to stresses and fatigue from a variety of sources (e.g., vibration, extreme temperature cycles, repair stresses, material fatigue, and micrometeoroid damage). Additionally, cracks, dents, and breaks may be the result of inadvertent mishandling during maintenance of the vehicle. Such damage may or may not appear significant; however, due to the stressful environment of launch/takeoff, space travel, and reentry, minor blows may lead to major cracks.

The types of inspection to detect such cracks will vary depending on the structural material. For example, on aluminum structures a visual inspection may be sufficient; however, on composite structures non-invasive techniques must be used, such as a remote-field eddy current method. Additionally, the RLV owner will need to provide damage tolerance data so that a valid inspection plan for each principal structural element can be developed to ensure cracking (initiated by fatigue, accident, or corrosion) will never propagate to failure prior to detection. In particular, damage tolerance to integral fuselage[30] and sandwich composite materials[31] is an area of on-going research. Due to the nature of these structures, damage tolerance analysis is more complex than conventional structures.

Of note: some aluminum alloys (i.e. Al-Mg-Li and Al-Mg-Sc) used for integral fuselage research have exhibited unacceptable critical properties: insufficient thermal stability and accelerated fatigue crack propagation.[32]

Sched Maint GI - 2.Turnaround Maintenance - Thermal Protection Subsystem Inspections

Guideline Input

During Turnaround Maintenance, the RLV Operator shall perform an inspection of the Thermal Protection Subsystem (TPS) in accordance with the Maintenance Manual.

Rationale

During turnaround maintenance inspection of an active TPS, the following items should be verified:

1. Coolant or other materials used are still operationally viable after being exposed to extreme conditions (temperature and pressure).
2. Coolant circulation and ejection systems are fully functional.
3. Protective surfaces are free of fractures.

The TPS has to function in an extremely hostile environment. Relatively minor issues can be exaggerated in this environment to cause a mishap. Inspections need to include identifying any effects of rain erosion, space debris and micrometeorites, gaps from thermal effects, deflections of the airframe, material changes from extreme temperatures, loosened parts from vibration, melting, deformation (especially at leading edges of wings and nose cone), tears, frays and breaks in fabrics, and the integrity of bonding materials, gap fillers and adhesives.

Inspections need to take advantage of advanced non-destructive inspection technology. Temperature history during reentry from sensors in subsurface may be used to target specific areas for more detailed inspection.

Sched Maint GI - 3. Environmental Control and Life Support System Scheduled Maintenance

Guideline Input

The RLV Operator shall perform an inspection of the Environmental Control and Life Support Subsystem (ECLSS) during Turnaround Maintenance and following any maintenance activity that may affect the ECLSS, in accordance with the Maintenance Manual.

Rationale

The ECLSS is critical to the ability of the pilot/crew to perform as part of the Flight Safety Subsystem.

Post-flight replenishment, maintenance, repair, or testing of an environmental control and life support system should also ensure the primary and backup systems are maintained within specifications as part of the Return to Service inspection.

Sched Maint GI - 4.Propulsion System Repair and Overhaul

Guideline Input

Propulsion System repair and overhaul shall return the RLV to flightworthy condition per the Maintenance Manual.

Rationale

Current propulsion technologies often employ an extremely complex set of piping, valves, combustors/igniters, and gimbal actuators to perform engine control and combustion. The RLV developer/operator needs a clear and complete set of maintenance procedures for ensuring Propulsion Subsystem maintenance is done correctly.

Sched Maint GI - 5.Motor Refurbishment

Guideline Input

Motor refurbishment shall return the motor to flightworthy condition in accordance with the Maintenance Manual.

Rationale

Some RLV concepts will employ solid rocket motors. Motor refurbishment needs to be conducted to maintain the design specifications and to ensure reliability. While this technology is well known, motor refurbishment poses a potential safety risk to the public at the facility of refurbishment as well as a potential risk to the public during flight.

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Appendix A: Acronyms/Terminology

AAAF	Association Aéronautique et Astronautique de France
A&P	Airframe & Powerplant
A/C	Aircraft
AC	Advisory Circular
AD	Airworthiness Directive
ADIZ	Air Defense Information Zones
AETB	Alumina Enhanced Thermal Barrier
AFS	Aviation Flight Standards
AIAA	American Institute of Aeronautics and Astronautics
ALARA	As Low As Reasonably Achievable
AM	Amplitude Modulation
AMF	Astronauts Memorial Foundation
ANPRM	Advanced Notice of Proposed Rule Making
ANSI	American National Standards Institute
AOA	Abort Once Around
AOG	Airplane on Ground
APU	Auxiliary Power Unit
ARAC	Aviation Rulemaking Advisory Committee
ARC	Ames Research Center
ARF	Assembly and Refurbishment Facility
ARINC	Aeronautical Radio, Inc.
ARP	Aerospace Recommended Practice
ASEE	American Society for Engineering Education
ASICS	Application Specific Integrated Circuits
ASME	American Society of Mechanical Engineers
ASQ	American Society for Quality
AST	Office of the Associate Administrator for Commercial Space Transportation
ASTM	American Society for Testing and Materials
ASTWG	Advance Spaceport Technology Working Group
AWS	Aerospace Worthiness Standards
ATA	Air Transport Association
ATAC	Advanced Technology Advisory Committee
ATC	Air Traffic Control
ATM	Air Traffic Management
ATO	Abort to Orbit
ATOS	Air Transport Oversight System
ATSRAC	Aging Transport Systems Rule Making Advisory Committee

AVCS	Air Vehicle Control Station
BCSP	Board of Certified Safety Professionals
BFE	Buyer Furnished Equipment
BITE	Built In Test Equipment
BPSK	Bi Phase or Binary Phase Shift Keying
CAA	Civil Aviation Authorities
CAM	Civil Aeronautics Manual
CAR	Code of Aviation Regulations
CASA	Civil Aviation Safety Authority
CASS	Continuous Analysis and Surveillance
CAST	Civil Aviation Safety Team
CBM	Condition-Based Maintenance
C-Band	Frequency range between 3.6 and 4.2 GHz
CCAFS	Cape Canaveral Air Force Station
CDR	Critical Design Review
CEI	Contract End Item
CEO	Chief Executive Officer
CFR	Code of Federal Regulations
CIL	Critical Items List
CINCSPACE	Commander In Chief, Space Command
CMR	Certification Maintenance Requirements
CO_2	Carbon Dioxide
COFR	Certificate of Flight Readiness
COLA	Conjunction On Launch Assessment or Collision Avoidance
COMBO	Computation of Miss Between Orbits
COMSTAC	Commercial Space Transportation Advisory Committee
CONOPS	Concept Of Operations
CONUS	Continental United States
CRM	Cockpit Resource Management
CRV	Crew Return/Rescue Vehicle
CVR	Cockpit Voice recorder
dB	Decibel
DACUM	Developing A Curriculum
DARPA	Defense Advanced Research Projects Agency
DCC	Division of Community College
DCN	Document Change Notice
DFRC	Dryden Flight Research Center
DMS	Docket Management System

DNPS	Delaware North Park Services
DO	Delivery Order
DoD	Department of Defense
DOF	Degrees of Freedom
DOT	Department of Transportation
E_c	Casualty Expectation
EIS	Environmental Impact Statement
EFI	Enterprise Florida, Inc.
ELV	Expendable Launch Vehicle
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EOM	End Of Mission
EPA	Environmental Protection Agency
ERP	Emergency Response Procedure
ESA	European Space Agency
ESD	Electrostatic Discharge
ESMC	Eastern Space and Missile Center
ET	External Tank
ETMS	Enhanced Traffic Management System
ETOPS	Extended Twin (engines) Operations
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCC	Federal Communications Commission
FHA	Functional Hazard Assessment
FL	Florida
FM	Frequency Modulation
FMEA	Failure Modes and Effects Analysis
FMEA/CIL	Failure Modes and Effects Analysis/Critical Items List
FMECA	Failure Modes, Effects, and Criticality Analysis
FMS	Flight Management System
FOCC	Flight Operations Control Center
FOQA	Flight Operations Quality Assurance
FR	Flight Recorder
FRCS	Forward Reaction Control System
FRR	Flight Readiness Review
FSDO	Flight Standards District Office
FSO	Flight Safety Officer
FSS	Flight Safety Systems
FTA	Fault Tree Analysis
FTD	Flight Training Devices
FTS	Flight Termination Systems
FY	Fiscal Year

G	Gravitation Acceleration at Sea Level
GLONASS	Global Orbiting Navigation Satellite System
GNC	Guidance, Navigation, Control
GNSS	Global Navigation Satellite System
GOR	Ground Operations Review
GPS	Global Positioning System
GRC	Glenn Research Center
GSE	Ground Support Equipment
GSO	Ground Safety Officer
GSRP	Ground Safety Review Panel
GSS	Ground Support System
HAZMAT	Hazardous Material
HBAT	Handbook Bulletin for Air Transportation
HCF	High Cycle Fatigue
HDTV	High Definition Television
HMI	Human-Machine Interface
HMF	Hypergolic Maintenance Facility
HMR	Hazardous Material Report
HRST	Highly Reusable Space Transportation
HTHL	Horizontal Take Off and Landing
HTVL	Horizontal Take Off and Vertical Landing
HW	Hardware
IASA	International Aviation Safety Assessment
ICA	Instructions for Continued Airworthiness
ICAO	International Civil Aviation Organization
ICF	Instructions for Continued Flight-worthiness
ICHM	Integrated Control and Health Management
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
IFR	Instrument Flight Rules
ILL	Impact Limit Lines
ILS	Instrument Landing System
IMU	Inertial Measurement Unit
ISO	International Organization for Standardization
ISS	International Space Station
ITU	International Telecommunication Union

IVHM	Integrated Vehicle Health Monitoring
IV&V	Independent Validation and Verification
JAA	Joint Aviation Authorities
JAR_1	Joint Airworthiness Regulations
JAR_2	Joint Aviation Regulations
JAR-VLA	Joint Aviation Regulations-Very Light Airplanes
JROC	Joint Requirements Oversight Council
JSC	Johnson Space Center
Klb	Kilo Pound
Klbs	Kilo Pounds
KSC	Kennedy Space Center
Ku-Band	Frequency Range from 1.7 to 12.76 GHz
LA	Los Angeles
LCC	Launch Control Complex
LH2	Liquid Hydrogen
LOA	Letter of Agreement
LEO	Low Earth Orbit
LLC	Limited Liability Corporation
LOX	Liquid Oxygen
LRCS	Long-Range Communication System
LRU	Line Replaceable Units
MAKS	Multi-Purpose Aerospace System
MMEL	Master Minimum Equipment List
MEL	Minimum Equipment List
MLP	Mobile Launcher Platform
MMH	Monomethyl Hydrazine
MNPS	Minimum Navigation Performance Specifications Airspace
MPP	Maintenance Program Plan
MRB	Maintenance Review Board
MRM	Maintenance Resource Management
MRO	Maintenance, and Repair, Overhaul
MSFC	Marshall Space Flight Center
MSG	Maintenance Steering Group
MSI	Maintenance Significant Items
MSL	Mean Sea Level
N/A	Not Applicable
NAI	National Aerospace Initiative
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASP	National Aerospace Plane
NAT	North Atlantic

NDE	Non Destructive Evaluations
NFPA	National Fire Protection Association
NIDA	NIDA Corporation
NORAD	North American Aerospace Defense Command
NOTAM	Notice To Airmen
NOTMAR	Notice To Mariners
NPRM	Notice of Proposed Rulemaking
NSP	National Simulator Program
NSLD	NASA Shuttle Logistics Depot
NSTS	National Space Transportation System
NTSC	National Television System Committee
O_2	Oxygen
O&M	Operations and Maintenance
O&S	Operations and Supportability
OEI	One Engine Inactive
OEM	Original Equipment Manufacturer
OJT	On-the-Job Training
OMD	Operations and Maintenance Document
OMDP	Orbiter Maintenance Down Period
OMI	Operations and Maintenance Instructions
OMRS	Operations and Maintenance Requirements Specifications
OMRSD	Operations and Maintenance Requirements Specifications Document
OMS	Orbital Maneuvering System
OPF	Orbital Processing Facility
ORR	Orbiter Readiness Review
OSD/AF	Office of Scientific Development/Air Force
OSHA	Occupational Safety and Health Administration
OSI	Open Systems Interconnect
P_i	Probability of Impact
PAL	Phase Alternation Line
PCM	Pulse Code Modulation
PiC	Pilot in Command
PLC	Programmable Logic Controller
PMA	Parts Manufacturer Approval
PMD	Propellant Management Devices
PMI	Principle Maintenance Inspectors or Preventative Maintenance Inspection
PoC	Point of Contact
PRACA	Problem Reporting and Corrective Action

PRR	Payload Readiness Review
PSI	Pounds per Square Inch
PSRP	Payload Safety Review Panel
Pt.	Part
PVAT	Position, Velocity, Attitude, Time
Q-D	Quantity Distance
QD	Quick Disconnects
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RCM	Reliability Centered Maintenance
RCS	Reaction Control System
RF	Radio Frequency
RLV	Reusable Launch Vehicle
RNAV	Area Navigation
RPM	Revenue Passenger Mile
RPR	Rulemaking Project Record
RPSF	Rotation, Processing & Surge Facility
RSO	Range Safety Officer
RSRM	Reusable Solid Rocket Motor
RSS	Range Safety System
RTG	Radioisotope Thermoelectric Generator
RTI	Research Triangle Institute
RTLS	Return To Launch Site
RTS	Return To Service
RTV	Room Temperature Vulcanizing
RVT	Reusable Vehicle Test
SAE	Society of Automotive Engineers
SATMS	Space and Air Traffic Management System
SCAPE	Self-Contained Atmospheric Protective Ensemble
SDP	Safety Data Package
SDR	Service Difficulty Report
SFE	Supplier Furnished Equipment
SGS	Space Gateway Support
SIAT	Shuttle Independent Assessment Team
SLF	Shuttle Landing Facility
SLI	Space Launch Initiative
SME_1	Shuttle Main Engine
SME_2	Subject Matter Expert
S/N	Stock Number
SNPRM	Supplemental Notice of Proposed Rule Making
SOH	State of Health
SOP	Standard Operating Procedure
SPST	Space Propulsion Synergy Team

SRB	Solid Rocket Booster
SRD	Systems Requirements Document
SRM	Solid Rocket Motor
SRSO	Senior Range Safety Officer
SSA	System Safety Assessment
SSB	Single Side Band
SSME	Space Shuttle Main Engine
SSP	Space Shuttle Program
SSTO	Single Stage To Orbit
SSV	Space Shuttle Vehicle
STC	Space Traffic Control
STS	Space Transportation System
SUA	Special Use Airspace
SUP	Suspected Unapproved Parts
SW	Software
TAL	Transoceanic Abort Landing
TBD	To Be Determined
TCAS	Traffic Alert and Collision Avoidance System
TOGA	Takeoff/Go-Around
TOL	Transoceanic Landing
TPS	Thermal Protection System
TSA	Transportation Security Administration
TSO	Technical Standard Order
TSOA	Technical Standard Order Authorization
TSPI	Time Space Position Information
TSTO	Two Stage To Orbit
TTS	Thrust Termination System
TVC	Thrust Vector Control
UAV	Unmanned Aerial Vehicle
US	United States
USAF	United States Air Force
USBI	United States Boosters, Inc.
USC	United States Code
VAB	Vehicle Assembly Building
VFC/MFC	Maximum Speed For Stability Characteristics
VDF/MDF	Demonstrated Flight Diving Speed
VFR	Visual Flight Rules
VHF	Very High Frequency
VOR	VHF Omnidirectional Range (navigation system)
VSP	Vision Spaceport Program
VTHL	Vertical Take Off and Horizontal Landing
VTVL	Vertical Take Off and Landing
WSMC	Western Space and Missile Center
WWI	World War 1
Wx	Weather

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Appendix B: RLV Guideline Input Suggestion Form

RLV Guideline Input Suggestion Form

Name: ____________________________ Company Name: _________________
Address: ____
City: _______________ State, Postal Code, Country: ____________________
Phone: ___________________________ Date: ____________________________
Email: ____

Document: RLV O&M Guideline Inputs – Vol. 3 – Maintenance
Sec: ______ Page: ____ Line: _______

[ ] Documentation Error (Format, punctuation, spelling)

[ ] Content Error

[ ] Enhancement or Refinement

Rationale (Describe the error or justification for enhancement):
____
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Proposed change (Attach marked up text or proposed rewrite):
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Please provide any general comments for improvements of this document:

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Return completed form to:

FAA/AST-100
RLV O&M
800 Independence Ave SW RM 331
Washington DC 20591

Appendix C: Traceability of Maintenance Function Decomposition

Figure 5 reflects the Maintenance Functional Decomposition as developed for this effort. The following figure, Figure 6, reflects the Maintenance Functional Decomposition as developed for a previous tasking effort. The subsequent table, Table 4, provides the sub-function level traceability between the two decompositions. The current decomposition was developed in preparation of a Functional Analysis.

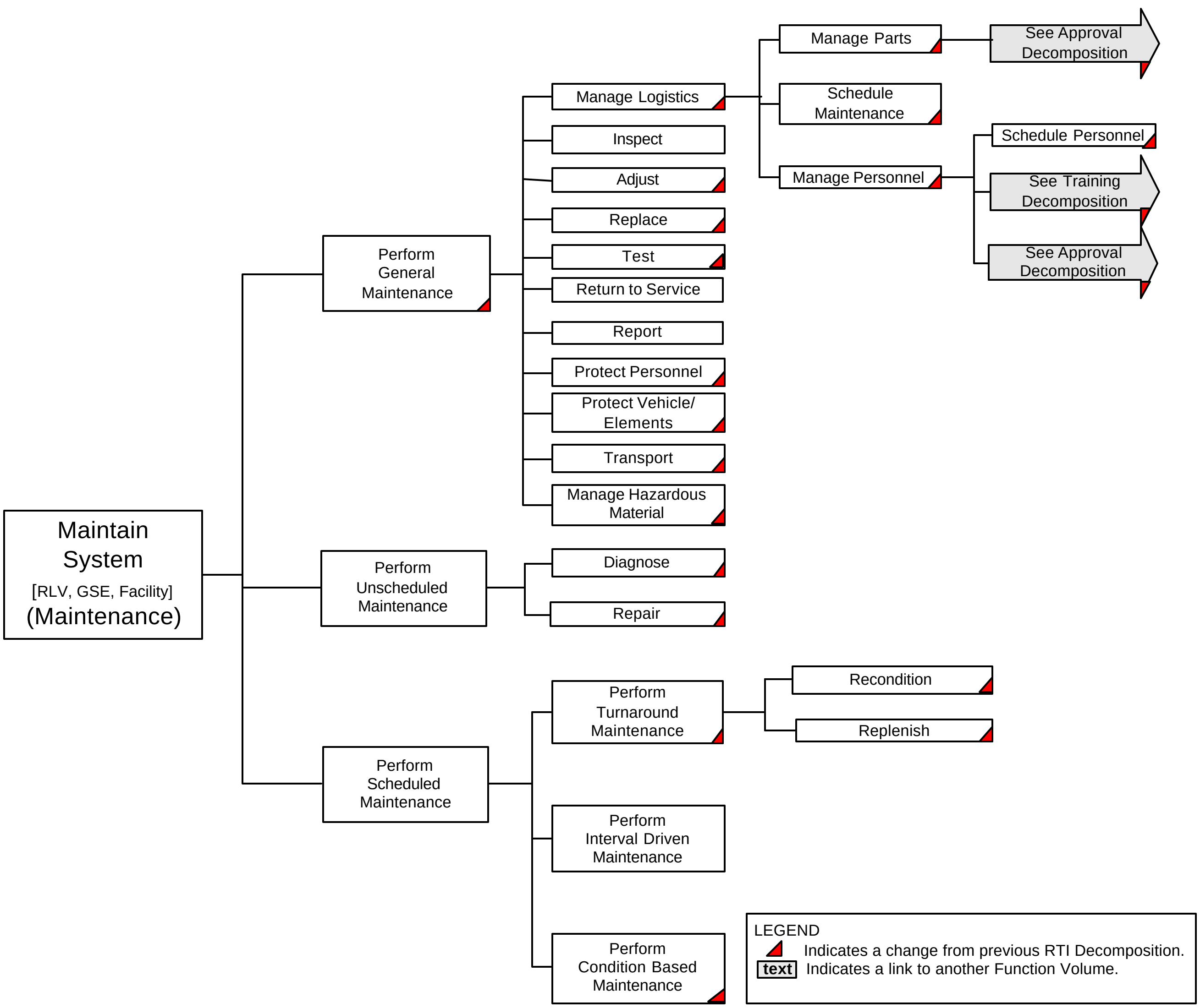

Figure 5 Current Maintenance Functional Decomposition

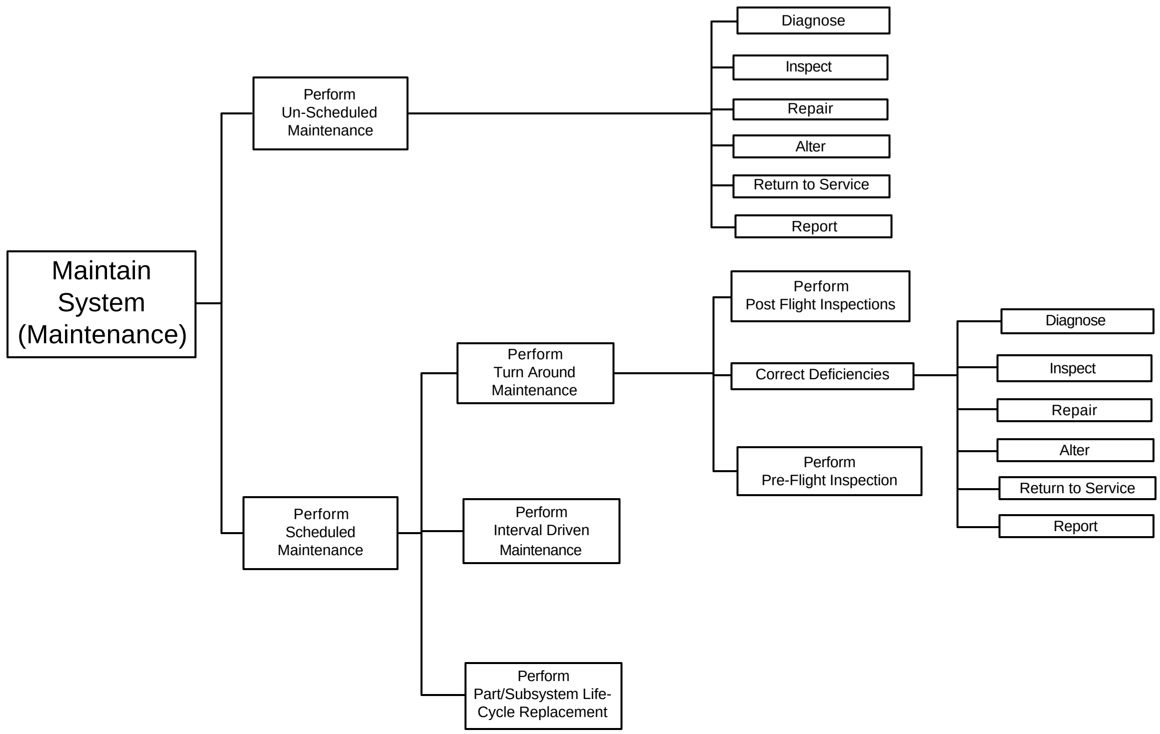

Figure 6 Previous Maintenance Functional Decomposition

Table 4 Maintain System Sub-Function Traceability

Indicates Same from Previous to Current	Indicates Move from Previous to Current	Indicates New Sub-Function	Indicates no Previous to Current Correlation

Current Sub-Functions					Previous Sub-Functions				
High Level Function	**Second Level Sub-Function**	**Tertiary Sub-Function**	**Fourth Level Sub-unction**	**Change**	**High Level Function**	**Second Level Sub-Function**	**Tertiary Sub-Function**	**Fourth Level Sub-unction**	**Change**
Perform General Maintenance				New Name					
	Manage Logistics			New					
		Manage Parts		New					
			See Approval Decomposition	New					
		Schedule Maintenance		New					
		Manage Personnel		New					
			Schedule Personnel	New					
			See Training Decomposition	New					
			See Approval Decomposition	New					
	Inspect			Moved from Perform Unscheduled Maintenance					
	Test			New					
	Return to Service			Moved from Perform Unscheduled Maintenance					
	Report			Moved from Perform Unscheduled Maintenance					
Perform Unscheduled Maintenance	Perform Unscheduled Maintenance			Same	Perform Unscheduled Maintenance				Same
	Diagnose			Same		Diagnose			Same
	Repair/Adjust			New - Combined 2 DO3 sub-functions: Repair and Alter		Repair			Same
						Alter			Changed to Adjust
Perform Scheduled Maintenance				Same	Perform Scheduled Maintenance				Same
	Perform Turnaround Maintenance			Same		Perform Turnaround Maintenance			Same
		Recondition		New			Perform Post Flight Inspections		Moved to General Maintenance
		Replenish		New			Correct Deficiencies		Moved to General Maintenance
								Diagnose	Moved to Unscheduled Maintenance

Current Sub-Functions					Previous Sub-Functions				
High Level Function	**Second Level Sub-Function**	**Tertiary Sub-Function**	**Fourth Level Sub-unction**	**Change**	**High Level Function**	**Second Level Sub-Function**	**Tertiary Sub-Function**	**Fourth Level Sub-unction**	**Change**
								Inspect	Moved to General Maintenance
								Repair	Moved to Unscheduled Maintenance
								Alter	Moved to Unscheduled Maintenance
								Return to Service	Moved to General Maintenance
								Report	Moved to General Maintenance
							Perform Pre-Flight Inspection		Moved to General Maintenance
	Perform Interval-driven Maintenance			Same		Perform Interval-driven Maintenance			Same
	Perform Condition-Based Maintenance			New		Perform Part/Subsystem Life-Cycle Replacement			Replaced

Endnotes

[1] White Paper on Commercial Space Transportation Reusable Launch Vehicle Operations and Maintenance, FAA-AST, Chuck Larsen, October 1999

[2] Reusable Launch Vehicles Operations and Maintenance Top-Down Analysis Final Technical Report, RTI, September 30, 2002 (RTI Report No. 08087.002)

[3] FAA Research/Human Factors in Aviation Maintenance and Inspection/ATA Specification 113 Maintenance Human Factors Program Guidelines, 1989 - 2002

[4] 49 CFR Part 172, Hazardous Materials: Hazardous Substances, Research and Special Programs Administration, Department of Transportation

[5] Aviation Safety Network, February 7, 2001, http://aviation-safety.net/database/2001/010207-1.htm

[6] United Space Alliance, http://www.unitedspacealliance.com/about/

[7] Advisory Circular 43-16A, Aviation Maintenance Alerts, FAA, November 2001, http://av-info.faa.gov/data/alerts/2001_11.pdf

[8]Aviation Week & Space Technology, Intelligence Indicates Shuttle Is Target, Craig Covault, June 6, 2002, Intelligence Indicates Shuttle Is Target, Aviation Week & Space Technology, Craig Covault, June 6, 2002, http://www.aviationnow.com/avnow/news/channel_space.jsp?view=story&id=news/sobl0606.xml

[9]Homeland Security Wants Aircraft Security Tightened Over Holidays, World Net Daily, November 29, 2003, Homeland Security Wants Aircraft Security Tightened Over Holidays, World Net Daily, November 29, 2003, http://www.intelmessages.org/Messages/National_Security/wwwboard/messages_03/6444.html

[10] Department of Defense Explosive Safety Board, General Information-Functions, http://www.ddesb.pentagon.mil/function.html

[11] http://catless.ncl.ac.uk/Risks/8.49.html#subj2

[12] Therm-Omega-Tech, Inc, http://www.thermomegatech.com/pg016H.html

[13] Columbia Accident Investigation Board Volume 1, Columbia Accident Investigation Board, August 2003

[14] Observations on FAA and Industry Efforts to Address Concerns about Aircraft Wiring, U.S. Department of Transportation, Alexis M Stefani, October 5, 2000, http://www.oig.dot.gov/show_pdf.php?id=35

[15] Shuttle Grounding, AMSAT, Sept 1999, http://www.amsat.org/amsat/archive/sarex/199909/msg00011.html

[16] The Explosion of the Ariane 5, Douglas N. Arnold, August 23, 2000, http://www.ima.umn.edu/~arnold/disasters/ariane.html

[17] Software QA/Test Test Resource Center, 1996-2004, http://www.softwareqatest.com/qatfaq1.html#FAQ1_3

[18] Software Error Plagued Guam Airport Radar System, CNN Interactive, Jackie Shymanski, August 10, 1997, http://www.cnn.com/WORLD/9708/10/guam.crash/

[19] Software Conformity Assessment, Underwriters Laboratory, Janet Flynt and Laura Elan, http://www.ul.com/software/SoftwareConformityAssessment.pdf

[20] The Silent Emergency (Pneumatic System Malfunction), FAA-P-8740-52 AFS-820 2000, Aviation Safety Program, 2000

http://www.parker.com/ag/nad/pdf/FAA%20Publications/FAA-P-8740-52.pdf

[21] Survey of Nondestructive Methodology for TPS Vehicle Health Monitoring for Reusable Launch Vehicles, David L. Huestis, SRI International, 2000, http://www-mpl.sri.com/projects/pyu2278.html

[22] Department of Defense Explosive Safety Board, General Information-Functions, http://www.ddesb.pentagon.mil/function.html

[23] National Transportation Safety Board, Database of Accident/Incident Information, http://www2.ntsb.gov/ntsb/query.asp

[24] A Guide for the Design of Highly Reusable Space Transportation, Space Propulsion Synergy Team, NASA/KSC

[25] Five to ten year vision for CBM, ATP Fall Meeting – Condition-Based Maintenance Workshop", USA, Atlanta, GA, Mitchell, J. S., 1998 (PowerPoint Presentation), http://www.atp.nist.gov/files/3

[26] Prognostics and Condition-Based Maintenance (CBM) A Scientific Crystal Ball, Pacific Northwest National Laboratory, Don Jarrell, Daniel Sisk, Dr. Leonard Bond, http://www.pnl.gov/dsom/publications/36771.pdf

[27] Availability, Prediction and Analysis, Wil Harkins, NASA/JSC, 1994

[28] Department of Defense Explosive Safety Board, General Information-Functions, http://www.ddesb.pentagon.mil/function.html

[29] Columbia Accident Investigation Board Volume 1, Columbia Accident Investigation Board, August 2003

[30] Crack Turning Damage Tolerance Approach for Integrally Stiffened Structure, 19th ICAF Symposium, International Committee on Aeronautical Fatigue; Pettit, R.G; Newman, J.C.; Domack, M.S.; Edinburgh, June, 1997, http://www.cfg.cornell.edu/projects/CrackTurning/Crack_TurningProj.html

[31] Review of Damage Tolerance for Composite Sandwich Airframe Structures, Final Report, DOT/FAA/AR-99/49, August 1999, http://research.faa.gov/aar/tech/docs/techreport/99-49.pdf

[32] New Aluminum Alloys And Fuselage Structures In Aircraft Design, Gerhard Tempus, May 18, 2001, http://www.mat.ethz.ch/news_events/archive/materialsday/matday01/pdf/TempusMD.pdf